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Satellites Today

microwaves to movies.

The Complete Guide to Satellite Television

by Frank Baylin

with Amy Toner

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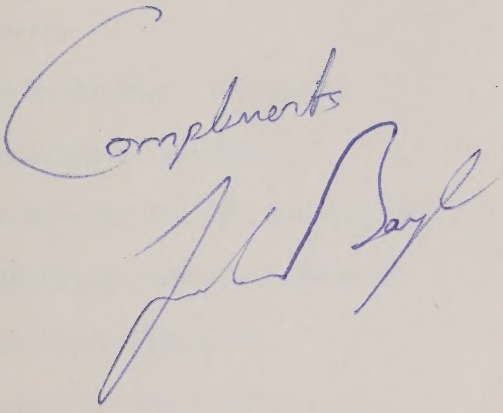

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INTRODUCTION
HARNESSING THE COSMOS

There is a revolution occurring in the way man communicates that will affect him and his way of life like none has before. We have seen how the computer has changed everything from business to the way our children entertain themselves. The changes that are occurring because of the newly discovered methods of detecting, understanding, and manipulating invisible radio waves from satellites are no less revolutionary.

In recent years satellite antennas have become a common sight. They are part of the communication system that now allows more than fifty channels to be received by a television set. The revolutionary technology makes it possible for national and even global computer networks to exchange information.

In the short life of the satellite communication industry, costs of "earth stations" have been dramatically reduced. Less than 15 years ago a satellite receiving station could cost a million dollars. Now these "earth stations" are so inexpensive and simplified that even a competent "do-it-yourselfer" can receive signals in his backyard from many satellites!

The everyday use of the satellite now allows businessmen in cities scattered over the globe to meet in privacy using television. A whole new breed of television broadcasters relay entertainment and information by satellite from the largest cities to the most remote corners of our nation and our globe.

1. THE PIONEERS

Anyone who chooses to use a satellite communication system is in a situation unique in the history of mankind. Until a few short years ago we could not view the myriad of television programming available today. Today the old model of "TV viewing" is being revolutionized by our advancing technology. It is fascinating to see how far we have come in an incredibly short time.

Electromagnetic or radio waves were first measured less than 80 years before the launching of the first communication satellite. In 1888 the German physicist Heinrich Hertz demonstrated that the wavelengths of radio waves can vary in size from centimeters to meters. He discovered that these invisible waves and light each have a velocity of 186,000 miles per second, and exhibit similar properties of reflection, refraction, and polarization. This new discovery paved the way for a telecommunication explosion.

In 1896 the first wireless radio signals were successfully transmitted. Guglielmo Marconi, an Italian scientist, sent radio signals 9 miles, an amazing distance at that time. These signals were a combination of long and short "clicks" that were played over a loudspeaker and were then translated into either dots or dashes, as in the familiar Morse code. Five years later Marconi flashed a message in radio waves from England to Newfoundland.

Scientists were not the only ones interested in communicating via the new-found technology. Amateur radio operators—"hams"—were allocated the short-wavelength signals since the longer ones had already been claimed by the pioneers and scientists. A 100-meter shortwave message was transmitted transatlantically by hams in 1923.
In 1900 Reginald Fessenden, an American, first transmitted a human voice, although poorly articulated, one mile over radio waves. Then in 1906 he successfully radioed a distance of 200 miles to New York state and was unintentionally overheard in Scotland! These discoveries led to the nation's first commercial radio station, KDKA, which had its

premier broadcast on November 2, 1920. Before long, other radio stations were springing up all over the country.

For the first time, the public could be reached instantly. This revolutionary change in communication inspired much enthusiastic experimentation and invention. Short-wave (SW) broadcasts could travel around the world in a matter of less than a second, and were used by both hams and commercial companies. The commercial broadcasters were allocated the relatively shorter AM wavelengths. In 1935 Edwin Armstrong, an advocate of ultra short waves, demonstrated a new broadcasting system, FM, which was an improvement over AM radio. Derived from the abbreviation for "frequency modulation," FM is relatively free of atmospheric disturbances and has an excellent tone.

The next important development in the use of radio waves was for the relaying of images over the air. In 1904 Arthur Korn, a German, first sent "wire-photos" 600 miles over a telephone line from Munich to Nuremberg. His transmission of wire photos from the European continent to England in 1907 was a sensation. The adage "A picture is worth a thousand words" could not have been more true than at this time of new discovery. In 1922 Korn demonstrated "phototelegraphy," in which a wireless receiver was hooked to a typewriter that printed various sized dots. In this manner, a picture could be "painted" in 40 minutes. The first transatlantic radio broadcast of pictures from London to New York was accomplished in 1924 by Richard Ranger, an American, using a more sophisticated device. His mechanism utilized a spot of light that scanned the picture to be sent. The reflected light was picked up by a photocell that converted the different intensities into electrical signals, which were then relayed by radio to a reciever that changed them into light. The light was projected onto film, which was subsequently developed and printed into photographs. These pioneering advances were to lead us rapidly to an electromagnetically connected world.

Television, a fixture that seems so familiar and natural to most of us, was not always the easy convenience it is today. Many scientists worked and experimented before television, as we know it now, was developed. The very first references to television came in 1910 in the Kansas City Star. A story entitled "Television on the Way" described experiments by a French scientist. Some time passed before C. Francis Jenkins, an American TV pioneer, predicted in 1922 that "motion pictures by radio in the home and an entire opera some day may be shown without the hindrance of muddy roads."

In 1884 Paul Nipkow, a German, invented the Nipkow disk, which dissected an image into fragments of light for detection and subse-

quent broadcast. In order for these fragments to be reassembled into an image, it was necessary to invent a device to recreate the picture. The step that paved the way for such a breakthrough was the invention of the cathode-ray tube by Sir William Crookes, a British scientist, although he considered his device of 1895 merely a scientific "plaything". The modern picture tube, developed by Vladimir Zworykin, is a sophistication of Crookes' "plaything." The Crookes tube used electron beams that illuminated a screen, but Zworykin was the first to demonstrate control of this electron beam solely by electronic signals. As a result, with the perfection of this technology, television could officially be introduced to the public at the 1939 New York World's Fair.

At the same time, scientists were working on another important technical advance, radar, which reached its peak of development during World War II. How does this revolutionary technology work? Radio waves are broadcast toward an object, and an antenna then scans for any reflected waves. The antenna shows any aircraft, birds, or other objects in a fraction of a second. During World War II the Congressional Record referred to radar as "the superweapon, the most revolutionary military device of this war." Radar was very important in the defense of Britain because a 24-hour watch of the North Sea coast could thus be maintained.

At the war's end radar used improvements made in the name of war to serve more peaceful purposes, as is so often the case with advances made during a war.

Radar technologies have been used for the transmission of "line-of-sight" television relays across the nation. Because TV signals have to be sent from relay to relay station to compensate for the earth's curvature, stations have to be installed along the way at intervals of approximately 30 miles. However, these relay stations were too expensive for use in broadcasting television to small, remote communities. The answer to this problem was the Community Antenna Television industry or, as it is commonly known, cable TV.

A cable TV company can come into an area and erect a master antenna, which will pick up any signals broadcast from the nearest large city. This master antenna is similar to an ordinary rooftop TV antenna but is much more powerful, e.g. often larger in size or of better quality or both. The messages are then relayed into any home that is willing to pay for the cable service. The cables are buried underground, strung alongside telephone wires, or in a few instances laid on top of the ground. In this way, people in remote areas are served with the same information as are their urban neighbors.

The most practical method of long-distance communication has come into being thanks to all of these preceding technologies. In keeping with mankind's tradition of combining fantasy and practical science to achieve the impossible, the history of satellite communication is filled with both dreamers and realists. In 1911 H. Gernsback suggested the use of radio, television, and radar in his science fiction book, *Ralph 124C41.* George O. Smith, in 1942, wrote a story entitled "Venus Equilateral" about a manned space vehicle orbiting the sun and designed specifically for communication. The most fascinating prediction of the future, however, was Arthur C. Clarke's article, "Extra Terrestrial Relays," appearing in the October, 1945 edition of Wireless World. It completely describes a worldwide communication network of geosynchronous satellites.

Satellite communication at first involved massive, expensive, and often unreliable equipment. Communication using microwaves in space was first accomplished in 1948 by the U.S. Army Signal Corp's Project Diana. By bouncing radar signals off the moon and back to earth again, they proved that relatively low power can be used to transmit and detect signals over very long distances. In 1954 the U.S. Navy successfully reflected the first voice messages from the earth to the moon and back again. Within two years of this first step, a U.S. Navy moon relay service was established between Washington, D.C. and Hawaii. Such long-distance communication was dependent only on the presence of the moon, with signals taking only a few seconds to travel to the moon and back. In the late 1950's the pace of satellite activity quickened. On October 4, 1957, the USSR launched the world's first satellite, Sputnik I. On New Year's Day, 1958, the U.S followed suit by launching its first satellite, Explorer I.

Various projects resulted from the launching of these first satellites. In 1958 Congress established the National Aeronautics and Space Administration in order to foster satellite communications and space exploration. The first NASA-sponsored satellite was SCORE, launched by the U.S. Air Force. SCORE was an important advance as it received messages at 150 million cycles per second, taped them, and then relayed the information back to earth at a different frequency of 122 million cycles per second. On December 19, 1958, President Eisenhower recorded and transmitted the very first satellite message, a Christmas greeting. SCORE's brief lifetime was just 12 days.

In 1959 the moon was used as a passive reflector for signals sent from the Bell Telephone Laboratories in Holmdel, N.J. A live voice was transmitted from the Bell Labs, to the moon, and then back to the Jet Propulsion Laboratories in Goldstone, California. This was the first of 17 tests of Project Moonbounce, which all used the moon as a

mirror for radio waves.

The next major project managed by these research centers (the Bell Telephone and the Jet Proplusion Labs) was to build the ground communication equipment for the Echo I, a passive satellite that functioned as an orbiting reflector. It was a 100-foot-high balloon made of Mylar only 5/10,000 of an inch thick launched an August 12, 1960. The signal Echo received from earth was only a millionth of a millionth of the original 10,000-watt uplinked signal. Even with this very weak signal, it demonstrated that two-way telephone conversations across the United States by satellite were possible.

The pace of these developments continued unabated. To test the feasibility of transoceanic communication via satellite, RCA designed and built the Relay satellite in 1961, thus improving the transmission of telephone, telegraph, and television messages across the ocean. In 1961 the Hughes Aircraft Corporation built Syncom, an experimental, active satellite that was to be launched into a 22,300 mile high geosynchronous orbit. In such an orbit Syncom would rotate at the same speed at which the earth rotated and would be stationary relative to any one location on the earth. In contrast, previous satellites that had been placed in elliptical orbits were only visible from any one location on the earth for limited periods of time.

Project Telstar, designed and built by AT&T and its Bell Telephone Laboratories, linked Europe and North America via television on July 10, 1962. This launched an explosion of activity that molded what we now know as the Information Age. Telstar was an active satellite because it contained a device called a "transponder" to receive, amplify, and retransmit signals to earth. Although radiation destroyed Telstar's electronics only 226 days after launch, it paved the way for the whirlwind advance of domestic and international satellite communication.

Relay I, launched by NASA on December 13, 1962, an active satellite similar in function and operation to Telstar, was the first satellite to link North and South America. On February 14, 1963, the first Syncom satellite was launched by NASA for Hughes Aircraft. An unsuccessful geosynchronous orbit was attempted; the communication system onboard did not operate. Only a few months after the failure of Syncom I, Telstar II, improved substantially over the earlier model because it was resistant to the radiation that put its predecessor out of commission, was launched into orbit for the Bell System by NASA. On July 26, 1963, two months after Telstar II, Syncom II was successfully placed into a geosynchronous orbit above the mouth of the Amazon River.

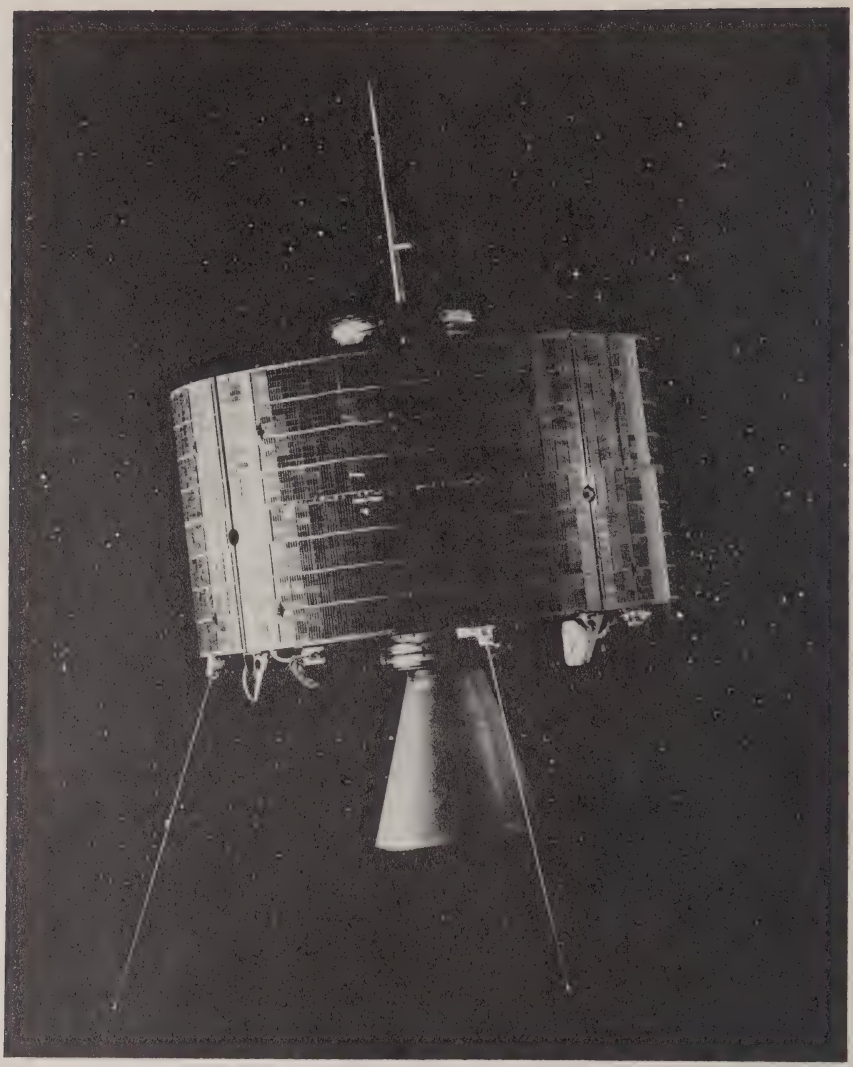


Figure 1-1. Syncom II. Syncom II, the world's first successful synchronous orbit communication satellite, was launched from Cape Canaveral on July 26, 1963 to open a new era in space communication. After completing initial experiments above the Atlantic Ocean between western Europe, Africa and the United States, the spacecraft was employed in a public demonstration at the ITU meeting in Geneva in 1963 during which delegates exchanged trans-Atlantic phone greetings with United Nations and U.S. government officials in New York and Washington. Later, the satellite was "walked" half-way around the world to a position above the Indian Ocean where it remained operational for over four years for the Department of Defense. Syncom II was decommissioned and retired from service in April 1969, more than five years after its normal span of life. (Courtesy of Hughes Aircraft Company).

Syncom III followed and relayed the 1964 Olympic Games in Tokyo to the United States and the 1964 World Series to Japan. On April 6, 1965, the first international satellite, Intelsat I or Early Bird, owned by the Intelsat Organization and built by Hughes Aircraft Company, was launched. Early Bird, so named because of its position in the far eastern sky, linked viewers and programmers in North America and Europe. Intelsat (the International Telecommunication Satellite Consortium) had been founded in 1964 to own and operate an international satellite communication system.

These pioneer vehicles have led the way to the launching of a myriad of increasingly sophisticated satellites. This has included more than 20 Intelsat vehicles, 12 Soviet Molniya satellites by 1969, and the more recent Soviet satellites Statsioner, Reduga, and Ekran. Indonesia has launched Palapa I for domestic communication; Canada has the Anik, and Japan has its Sakura series of satellies.

During the 1970's, the important experiments were underway that would provide information necessary for the development of an advanced and successful commercial satellite communication system. One such experiment was the Communications Technology Satellite (CTS) Program, a joint U.S./Canadian venture. It utilized the Canadian Anik series of vehicles, which were sent messages from earth to be retransmitted to 36 remote receiving stations. Furthermore, this ATS-6 satellite was also used in India and the Rocky Mountains in an experiment in which a spot beam from outer space covering 170,000 square miles was received using only $2000 worth of electronics. At least twenty of these powerful beams would have been needed to service all of the continental United States.

Today, the experiments and progress continue. More powerful and sophisticated satellites for broadcasting and for other special uses are being developed as the technology is improved.

Social and Economic Developments

The rapid advances in technology were accomplished by formation of new government institutions, laws, and businesses. Many present-day issues and problems in satellite communication were confronted in the earlier development of radio and television.

In the early days of radio (as is true today), producing and broadcasting programming had to be paid for in some fashion. Proposals ranged from attaching a coin box on all radios to transmitting radio shows over rented telephone lines. Advocates of free radio argued for freedom of the airwaves. AT&T finally solved the problem by offering time for sale to commercial sponsors. The rapid growth in the number

Figure 1-2 Early Bird. Early Bird, also called Intelsat I, the world's first commercial communication satellite, gets final adjustments in preparation for space-simulated vacuum tests at Hughes Aircraft Company, Los Angeles, California, which designed and built the spacecraft for Intelsat under management of the Comsat. The vehicle was launched on April 6, 1965, into a geosynchronous orbit 22,300 miles over the Atlantic to provide 240 two-way telephone channels or a two-way television channel between Europe and North America. The spacecraft could also handle teletype and facsimile at the same time it carried phone conversations. The satellite is no longer in service, having been replaced by more advanced Intelsats . (Courtesy of Hughes Aircraft Company).

of radio stations from 3 to 595 between January, 1922, and January, 1923 attested to the feasibility of the technology and the economic potential. Finally, in 1926, with the million-dollar purchase of station WEAF, the RCA network was formed. Radio had come of age.

In the same year, the Federal Radio Commission (FRC), predecessor of the Federal Communications Commission (FCC), was formed. The goal of this government body was to "make available, so far as possible, to all people of the United States, a rapid, efficient, nationwide and worldwide wire and radio communications service with adequate facilities at reasonable charges." Their regulation consisted almost entirely of issuing licenses on a first come, first served, basis.

Years later, the FCC played a more influential role in the development of television broadcasting. While cable TV companies were slowly bringing service to rural areas, the FCC was attempting to foster the use of UHF (Ultra High Frequency) channels in these isolated areas. However, UHF channels had characteristically poorer quality transmission than did the standard VHF (Very High Frequency, channels 2-13) broadcasts. The material being aired was also lower in budget and scope. As a result, cable TV was favored by many.

As cable companies realized profits in the endeavor of relaying already existing programming to remote areas, they began entering a new, profitable market, the highly populated urban centers. In the early 1960's cable companies began expansion into the business of purchasing, reselling, and often producing programming.

While cable television was growing, the technical and regulatory groundwork was being laid for the satellite telecommunication industry. In 1961 the United Nations adopted a resolution for the peaceful uses of outer space in the interest of world harmony. In 1962 President Kennedy signed the Communication Satellite Act to encourage and support growth in this area. Comsat, a private corporation established to plan, own, and operate a commercial satellite communication system and funded and regulated by the U.S. government, was given the sole rights to American participation in the launching and ownership of satellites for international use.

By 1965 the technical and economic developments in satellite communication prompted a number of large American corporations to enter the field without the financial aid of government or international institutions. ABC realized that a substantial savings of $25 million per year could be achieved through the use of satellites. To escape from being tied to terrestrial video circuits of AT&T, this network requested permission from the FCC to operate its own communication satellite. In response, the FCC asked for proposals from other parties in the private sector interested in developing a commercial satellite system

for the continental United States. RCA Global Communications suggested launching a system of three vehicles that would serve 300 earth-bound receiving stations, while CBS proposed a system for use by all the networks that would also carry PBS programs at no charge. Comsat responded by requesting the building of a similar system, which would also provide programming for cable TV stations and information for the press wire services. Teleprompter, Western Tele-Communications, AT&T, Hughes Aircraft/GT&E, Western Union, Fairchild Space and Electronics, and MCI/Lockheed/Comsat Satellite also expressed similar interests. Surprisingly, all estimates for such systems were within 20% of each other.

Because of the similarity in costs, the FCC was in a position to make a decision based on other factors in addition to cost. RCA and Western Union were chosen because they had technical expertise and sound business plans. Since these early days many companies have joined in building, launching, and operating satellites for all types of communication.

The cable TV industry began its participation in the satellite communication business at the beginning of the 1970's. Pioneers such as Irving Kahn, president of Teleprompter, realized that cable TV could offer greatly improved programming and service by using satellites. In June, 1973, the Canadian Anik satellite was launched by NASA and leased by RCA Americom Communications to become the first satellite to serve the American domestic market. The Anik was followed only one year later by the launching of Western Union's satellites, Westar I and II. On September 30, 1975, Home Box Office, a network catering to cable television, inaugurated pay TV services by broadcasting the Ali-Frazier boxing match, the "Thrilla in Manilla." To achieve the necessary link for this landmark production, RCA leased time on the Westar I vehicle. By the end of 1976 there were 130 earth receiving stations serving cable companies. By the 1980's every cable TV station in the country had one, and most often two or more, dish antennas as part of their sophisticated and essential earth stations.

Earth stations that only receive signals from outer space are not the unattainable commodities they once were. For example, in 1967/68 the first stations purchased by Comsat cost one quarter of a million dollars each. In 1976 the FCC approved the use of the smaller 4.5-meter (a diameter of 15 feet) dishes, and prices rapidly dropped from $75,000 to $25,000 for a dish antenna, a low noise amplifier, and two receivers. By the end of 1982 there were, by a conservative estimate, 45,000 home earth receiving stations installed in response to the rapid price reductions. By comparison, in 1980 and 1981 there were 5,000 and 15,000

private terminals, respectively. By 1983 a home earth station cost as little as $2000.

This continuing rapid drop in prices and increased availability of earth stations has taken us back full circle to issues similar to those faced in the early days of radio. We confront questions of the pirating of programming—a question of who pays the producers. The number of networks and programmers are rapidly increasing and, as a result, regulators such as the FCC and Congress are under pressure to quickly solve difficult problems. The rapid introduction of new technologies makes resolution of these issues even more complex and important.

2. REACHING FOR THE STARS—The Uplink

Every satellite communication circuit is composed of an uplink, a telecommunication satellite, and an earth receiving station (see Figure 2-1). The uplink beams messages in the form of radio waves into outer space just like a headlight of a car illuminates a dark road. Satellites receive these weak signals, amplify or boost their power, and then retransmit them back to earth. Earth stations, commonly known as TVRO (TV receive-only) stations, detect the very weak signal received

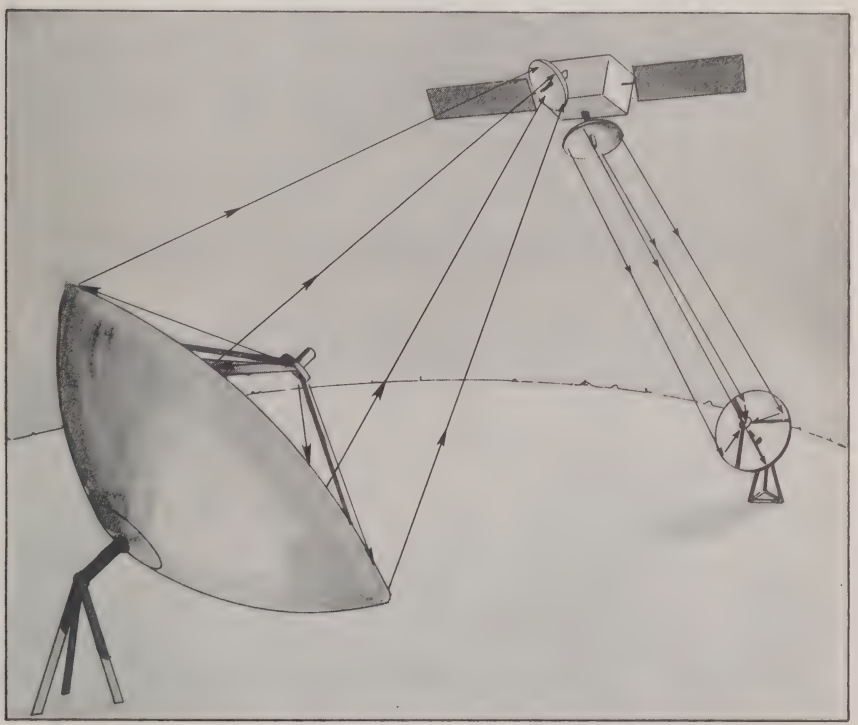


Figure 2-1 Satellite Communication Circuit. Broadcast signals are relayed by an uplink via satellite to an earth receiving station.

from space and extract the original message much like uplinks working in reverse. TVRO earth stations operate at much lower power levels than do uplinks, which must send signals powerful enough to reach a satellite located more than 22,300 miles away. Therefore, while both uplinks and receiving stations may be located anywhere "in view" of a satellite, uplinks are much more expensive and are more carefully regulated by the FCC. It is fortunate that homeowners and TV station operators can use the less expensive earth receiving stations and that transmissions from each sophisticated uplink can be detected by an unlimited number of TVROs.

Uplinks are used by many segments of the business community including TV and radio stations, telephone companies, and other institutions. In many cases an on-site uplink station is connected by direct cable links to broadcast studios, telephone lines, or computers. Many television stations relay signals by conventional, over-the-air methods to distant uplinks, which then send their signals to communication satellites. Many groups need uplink facilities on an occasional basis for teleconferencing, sporting events, or other special happenings. In such cases, the option of "taking Mohammed to the mountain" i.e., bringing the relay equipment directly to the action is an economical alternative to broadcasting over the air to a fixed uplink site. In addition, the leasing of portable uplinks complete with all equipment, including operating crews, is a viable path for other groups or institutions to follow, since owning a complete uplink is expensive. For example, an uplink cost from $250,000 to $660,000 in 1981. Thanks to these methods of relaying information into space, programmers can now reach national or even international audiences at affordable prices.

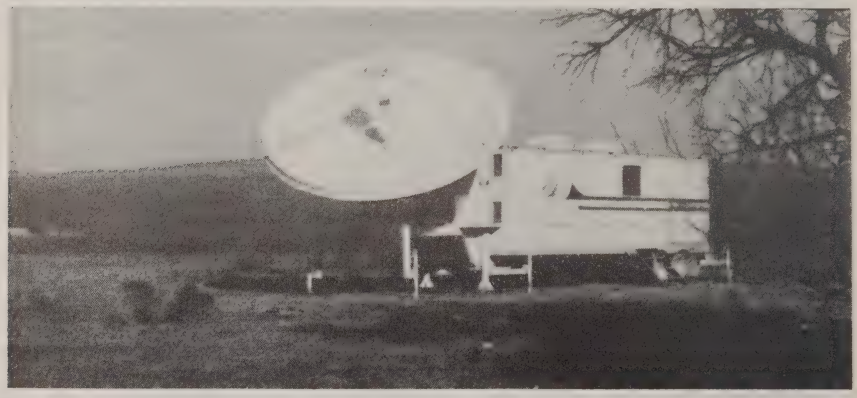


Figure 2-2 A Portable Uplink. The 3-piece, 5-meter antenna on a hydraulic mount can be set up to transmit to a satellite in two hours. All the electronic equipment is situated inside the 34 by 8-foot wide trailer. (Courtesy of the Public Service Satellite Consortium, PSSC).

The natural phenomena that ties programmers and audiences together and that links business information networks is the radio wave. The equipment that allows us to use radio waves is a triumph of modern technology.

What are Radio Waves?

Radio waves are the agent by which radio, television, satellite communication networks, and many other man-made devices work. What are these invisible but extremely useful phenomena of nature? If we could see a radio wave, it could be like the waves that travel outward in concentric circles when a pebble is tossed into a pond. Radio waves are also similar to the waves of vibrating air molecules that we know as sound, which travel through the air at 760 miles per hour. Radio waves, vibrations of electric and magnetic fields, travel much faster than sound at 186,000 miles per second, the speed of light. At this speed, a radio wave travels back and forth between the earth and a satellite almost instantly (actually in about half a second). An important property of radio waves is their frequency, the number of vibrations that occur every second (see Figure 2-3). Just as the frequency of sound vibrations determines whether a musical note is either a soprano or a bass, so the frequency of radio waves determines whether the vibrations may be in forms such as X rays or visible light. Radio waves sent

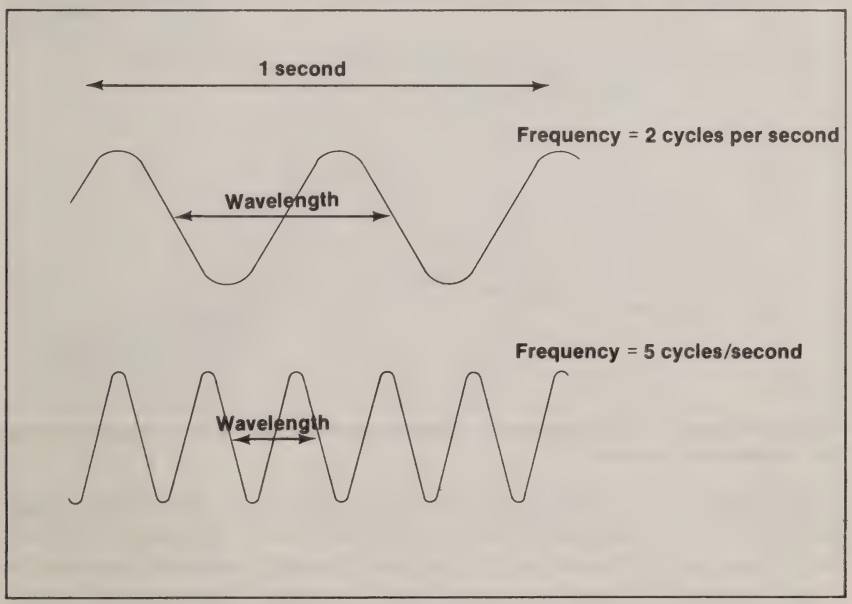


Figure 2-3 Radio Waves. The longer the wavelength is, the lower the frequency is, and vica versa. A 4-gigahertz signal (4 billion cycles per second) has a 7.5-centimeter wavelength.

from earth to satellites often have frequencies of approximately 6 billion cycles per second, abbreviated as 6 gigahertz. In addition to frequency, the wavelength of a radio wave, the distance in which one complete vibration occurs, is important. Since radio waves all travel at the same speed, one that has a shorter wavelength must have a higher frequency, and vice versa (see Figure 2-3).

Other important properties of radio waves are polarization and strength (see Figure 2-4). To understand this idea we can imagine a car driving along a highway. It can travel to the same destination by following a curving road along flat ground or by following a straight road over rolling hills. These types of movements are classified as

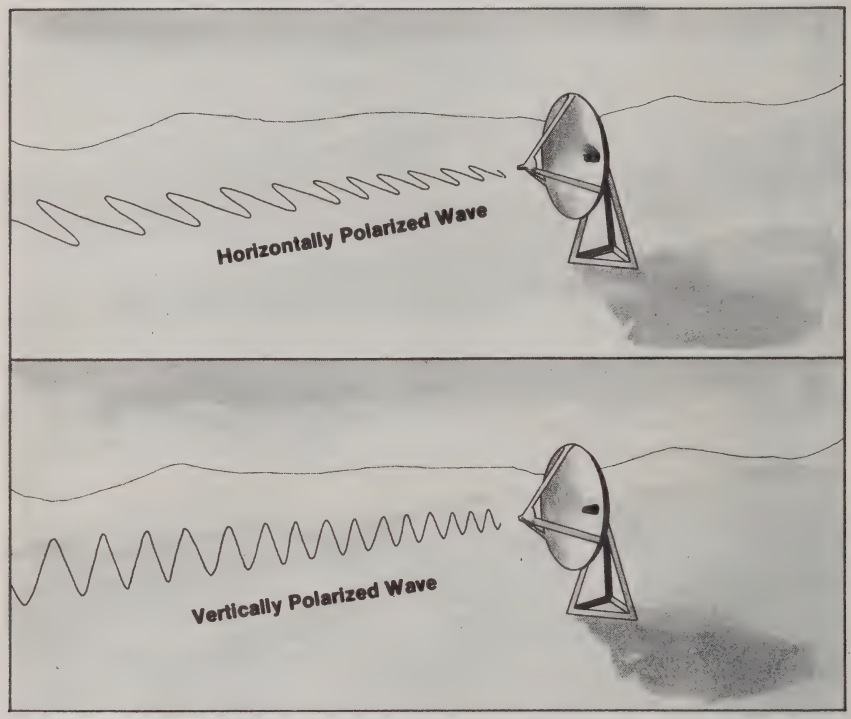


Figure 2-4 Vertically and Horizontally Polarized Radio Waves. These waves vibrate at right angles to each other.

either horizontal or vertical polarization. Although radio waves may have the same frequency and wavelength, their strength or power levels may not be the same. If the power is high, precautions must be taken to prevent damage to people and property. For example, microwave power levels near uplink antennas are high enough to cause serious burning or long-term damage such as eye cataracts; therefore, the uplink area must be securely fenced. In cases where uplinks are not

manned, the FCC requires that they be operated by remote control so that the danger of beam misalignment is reduced. There is no such problem with earth receiving stations at the other end of the satellite communication circuit, since they operate with low power levels comparable to those of a stereo system.

Many seemingly different phenomena encountered in nature including light, X rays, infrared heat rays, microwaves used in communication, and gamma rays from the cosmos are all radio waves (see Figure 2-7). Surprisingly, the only difference among them is their frequency. For example, the wavelength of visible light is comparable to the dimensions of atoms and molecules, and their frequencies are near billion cycles per second. In contrast, microwaves have lower frequencies of billions of cycles per second and wavelengths that range from meters to centimeters. Even lower frequency waves used in conventional radio transmission can be miles long.

Modern Methods of Communication

Until recently, man has been blind to all but those forms of radio waves known as light and infrared heat rays. As technology has improved, so has our ability to communicate. Morse code rapidly evolved to radio, television, and now to satellite telecommunication in less than a century. The same principles underlie all forms of radio wave communications.

Analog and Digital Signals—Coding the Message

Any message, whether it be the image and voice of an entertainer or details of stock-market transactions, must first be changed into a form that can be relayed by radio waves. If an analog coding method is used, the pattern of a message is mimicked by electrical voltages. For example, a voice can be changed into an analog signal by a microphone that creates a voltage determined by the loudness of the sound. The louder the sound, the higher the voltage. A digital coding method uses the numbers 0 and 1 to convey all information. For example, a voice could be expressed in digital form if the loudness at each point in time was expressed by numbers, or patterns of 0's and 1's. A photograph can also be described by a long series of 1's and 0's that are coded so that some impart information about the location of the dots composing the picture and others determine the brightness and color of the dots. Computers exclusively use digitally coded information.

Uplinks can relay either digital or analog forms of the same message. Converters that can translate between these two languages are available. For example, conversations between computers relayed by satellite are always digital, while most TV broadcasts are expressed in

analog form. However, the trend is to use digital broadcasts as newer and higher-quality television is developed and as satellites are packed with more sophisticated electronics allowing higher amounts of information to be transmitted.

Modulation—Adding the Message to Radio Waves

Analog or digital signals can be added onto radio waves by a process called "modulation." Once the message is modulated onto a radio wave (known as the carrier wave because it carries the information), it can be relayed from a sending to a receiving antenna. Radios, televisions, and other communication equipment demodulate the signals they receive; ie., they extract the original message from the carrier wave (see Figure 2-5).

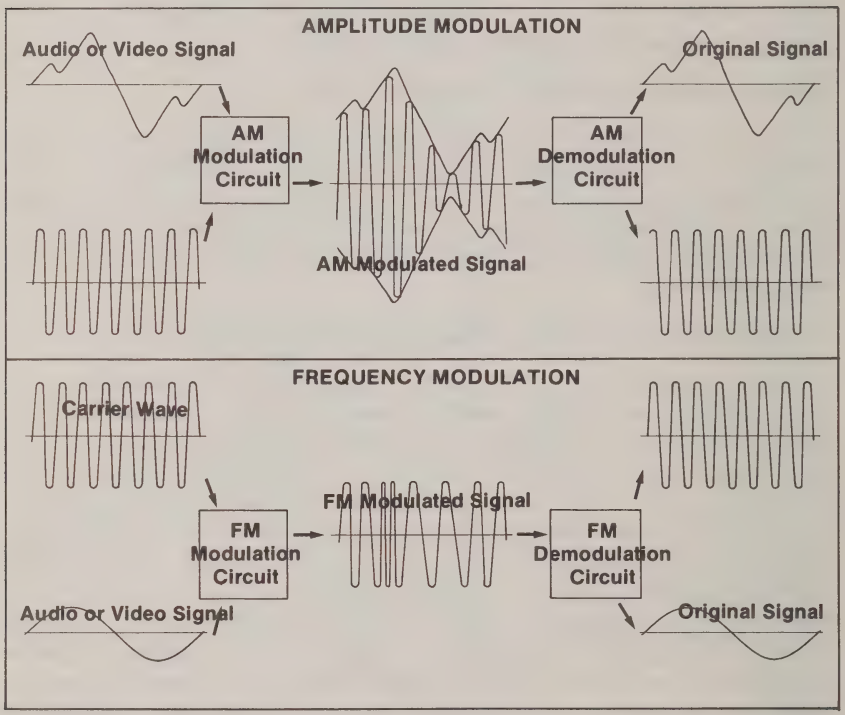


Figure 2-5 Amplitude and Frequency Modulation of Signals. The modulated audio, video, or data signal can be relayed by cables, over-the-air, or by satellite.

The simplest method to modulate a carrier wave is to switch it on and off. For example, Morse code is relayed as series of dots and dashes by turning the carrier wave on and off. The most familiar methods of modulation used today are amplitude modulation (AM) and frequency

modulation (FM) as encountered, for example, in AM and FM radio. In amplitude modulation, the power of a carrier wave is varied in accordance with the message being relayed,while in frequency modulation the frequency of the carrier wave is varied (see Figure 2-5).

Each type of modulation has advantages and disadvantages. AM messages must have high powers to travel long distances without being weakened too severely for clear reception. They are also more prone to picking up static than are FM messages. On the other hand, FM signals need relatively lower power for successful, long-distance transmission, but must use a substantially wider range of frequencies than AM messages would to carry the same amount of information. Satellite messages are frequency modulated for these reasons. As signals cover the long distances between earth-receiving-and-sending stations and satellites, the power becomes so low that AM relays would be unusable. Also, satellite communication relays use a very broad range of frequencies as is required by FM broadcasts.

Bandwidth—How Much Information Can be Carried?

Just as a large-diameter pipe can carry more water than a small one, a signal covering a wide band of frequencies can carry more information than can one covering a narrow band. This range of frequencies of radio waves is termed the "bandwidth." For example, if a television message is relayed in the frequency range from 54 million cycles per second (abbreviated 54 megahertz) to 58.2 megahertz, it would have a bandwidth of 4.2 megahertz. Each type of communication medium uses a characteristic bandwidth. Media such as television require a substantially wider bandwidth than do radio or telephone because much more information is necessary to recreate a picture than to recreate music or a voice. For example, a TV communication channel of the satellite Satcom III-R is located between the frequencies of 3.70 and 3.74 billion cycles per second, abbreviated as gigahertz. This channel therefore has a bandwidth of 40 megahertz. Voice channels, however normally require a bandwidth of only 3,000 to 4,000 cycles per second for quality sound reproduction.

Amplification—Increasing the Signal Strength

Messages beamed into space from an uplink antenna are weakened on their voyage to a satellite as the signal becomes spread out and is absorbed by water vapor, clouds, and other materials. This weakening is called "attenuation." Amplification, the opposite process, increases the signal strength. In the same fashion that a photograph is enlarged but not changed, amplification retains the original message. All televisions, radios, stereos, and other communication equipment amplify a signal before they demodulate carrier waves.

Noise—Hindering Clear Communication

In a perfect communication system, the signal would be relayed with no interference or noise. However, television or radio broadcasts are occasionally of poor quality or "noisy." Noise is present in all matter at temperatures above absolute zero, the temperature at which all molecular motion ceases. (There is no temperature colder than absolute zero). Noise is caused by the endless motion of the molecules that compose all matter. These small, vibrating charged particles generate radio waves that mask the organized signal sent by man. Noise from the environment becomes stronger as the temperature increases. Receiving antennas as well pick up more of this environmental noise as the signal bandwidth increases. Furthermore, noise is generated by internal heat in amplifiers, receivers, and other electronic equipment.

Noise is always present in satellite communication systems (see Figure 2-6). The quality of a communication is determined by the ratio of signal-to-noise power. For example, if a signal of 10 watts is received along with 5 watts of noise, the picture quality will be poorer than if a signal of 10 watts was received with 1 watt of noise. In the case of television, the signal must be at least 63,000 times the accompanying noise in order for a "high-quality" picture to be received.

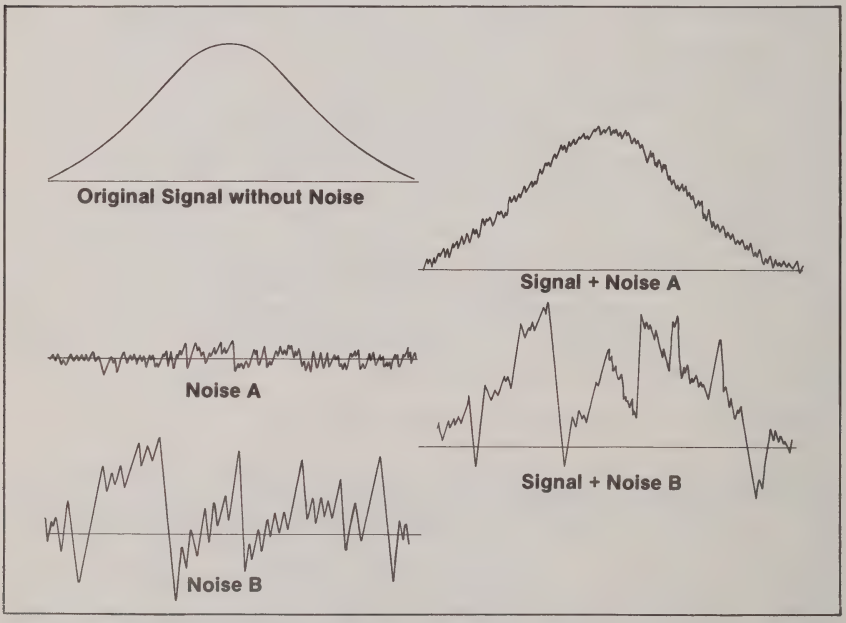


Figure 2-6 The Effect of Noise on a Radio or Television Signal. If the level of noise, as in case B, is too high the signal is garbled or even unintelligible.

FCC Radio Wave Allocations:

The Federal Radio Commission, and later, the Federal Communications Commission in concert with the International Telecommunications Union have kept order in the airways by successfully assigning portions of the radio wave spectrum to different communications media. In fact, the history of communications is unfolded by an exploration of these assignments of frequencies (Figure 2-7). As technology progressed, higher-frequency messages could be used. Wire transmission first began with relatively low frequencies, since the radio waves used by the pioneers were limited in frequency by the available electronics. When radio waves with frequencies higher than 1.5 megahertz were produced by man, the FRC delegated them to the "hams" because, at that time, they could not see a use for this region of the spectrum. As technology progressed further and new forms of communication were introduced, coaxial cable transmission, microwave relays, and then satellite communication were allocated successively higher frequencies. Even with all these new forms of communication, a relatively small portion of the electromagnetic spectrum is presently being used.

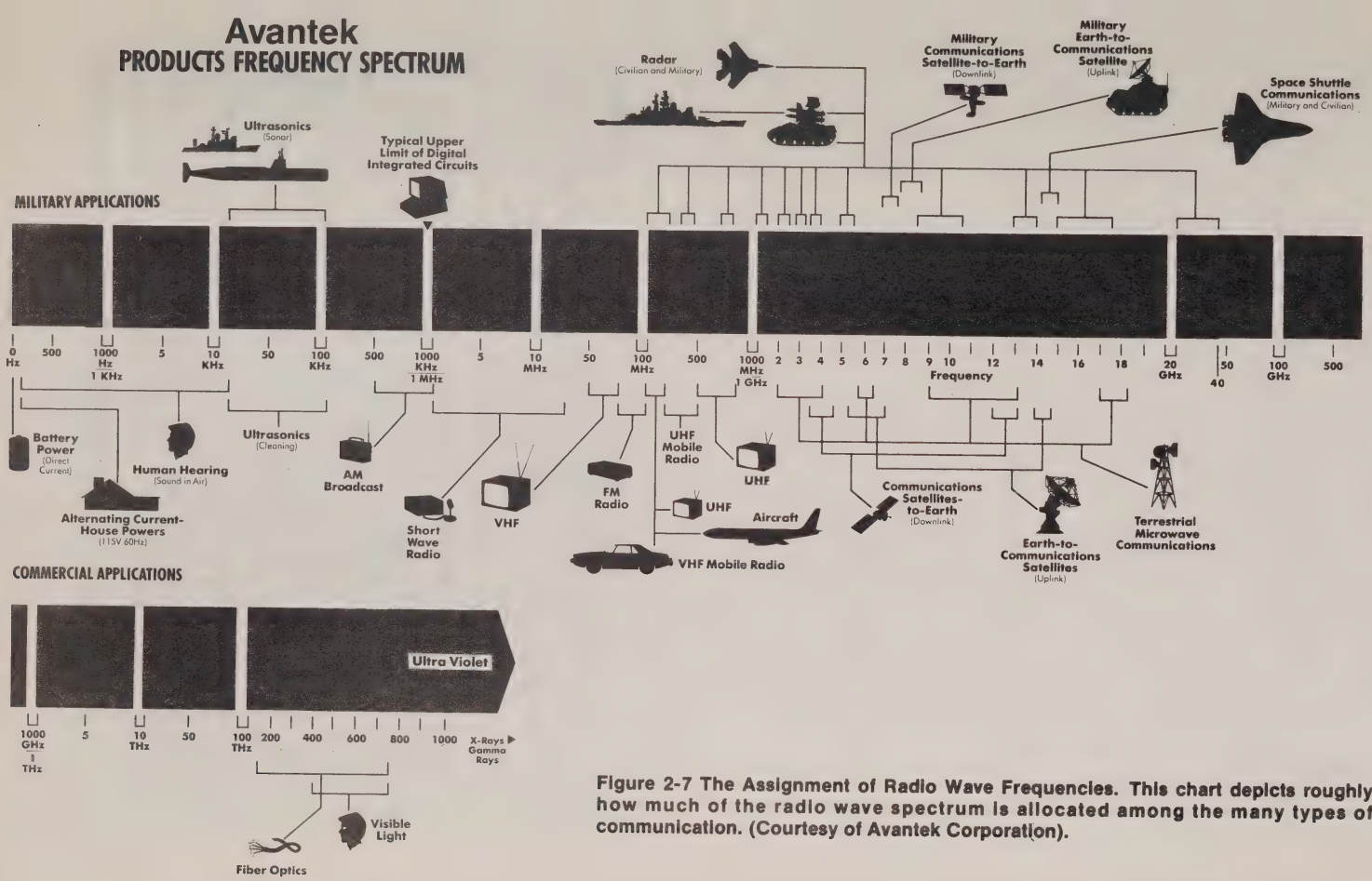


Figure 2-7 The Assignment of Radio Wave Frequencies. This chart depicts roughly how much of the radio wave spectrum is allocated among the many types of communication. (Courtesy of Avantek Corporation).

The table below show the general form of the allocation of radio wave frequencies. For example, TV channels 2, 3, and 4 use radio waves between 54 and 72 megahertz. Therefore, channel 2 uses one third of the band of radio waves between 54 and 60 megahertz and has a 6-megahertz bandwidth.

Table 2-1

FCC Assignment of Some Radio Frequencies

Frequency	FCC Assignment
(Megahertz)	
3-54	Mobile Radio
54-72	TV Channels 2-4 (VHF)
72-76	Radio Services
76-88	TV Channels 5 & 6 (VHF)
88-108	FM Radio
108-120	Aeronautical
120-136	Aeronautical
136-144	Government
144-148	Amateur Radio
148-151	Radio Navigation
151-174	Land, Mobile, Maritime, Government
174-216	TV Channels 7-13 (VHF)
216-329	Government
329-890	TV Channels 14-83 (UHF)

Why Microwaves?

Microwaves have been used in satellite communication for four specific reasons. First, higher-frequency radio waves aid in improving communication because, as the frequency increases, any given bandwidth becomes a smaller fraction of the operating frequency. For example, a 1-megahertz bandwidth located at 10 megahertz (10 million cycles per second) occupies relatively much more space than does the same bandwidth in the 10-gigahertz (10 billion cycles per second)

region of the spectrum. Since more space is available, wider bands with higher information capacity can be used at microwave frequencies. Therefore, microwaves can relay as much information as possible per satellite, thus paying off the expensive investment in satellites more rapidly.

A second reason for using microwaves is based on the need that uplink antennas have to aim a directional beam towards an extremely small target in space. Physics dictates that radio waves can be better focused by an antenna that has a size substantially larger than the wavelength of radiation. For example, sending a directional beam of AM radio signals with wavelengths of approximately 100 meters would require an extremely large, cumbersome, expensive antenna. Since microwaves of 6 gigahertz have wavelengths of approximately 5 centimeters or 2 inches, a 15-foot uplink antenna can aim most of its radiation into a very narrow beam, and relatively low power can be used.

Third, microwave transmissions to satellites or between line-of-sight stations are not as susceptible to noise from atmospheric disturbances as are lower-frequency transmissions. To illustrate, several times each year, for periods as long as two or three days, short-wave radio is useless for long-distance communication because sun-spot activity disturbs the reflection of radio waves by the upper atmosphere.

Fourth, the most important property of microwaves that determines their use in satellite communication is their ability to pass through the upper atmosphere into space. Below frequencies of approximately 30 megahertz, a radio wave beam will be reflected off the ionosphere layer in the atmosphere back towards the earth. Since microwave frequencies are far above the 30-megahertz range, they pass easily through the ionosphere layer shield.

Even though satellite communication is a young field, microwaves are being used as never before. As higher-frequency microwaves are also being recruited into service with improvements in technology (Figure 2-7) their use will be even more important to communication systems.

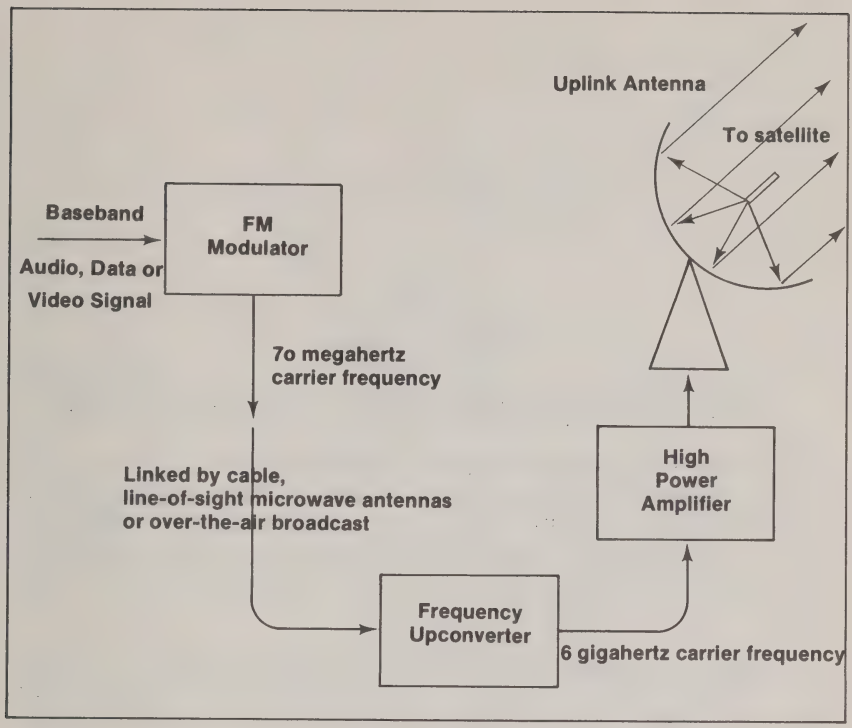


Figure 2-8 Typical Uplink Configuration. Radio, television, or computer information are all relayed to a communication satellite in a similar fashion.

3. OUTPOSTS IN SPACE—SATELLITES

Satellites are the key component in the telecommunication revolution. Our communication system is now greatly improved because any locations within a satellite's "view" can be linked without the use of expensive cables or line-of-sight relays. Furthermore, a communication satellite operating as a relay in space can serve vast areas of our globe at once.

Since these communication vehicles remain in one position relative to any chosen location on earth, they can effectively serve as high-volume, full-time switchboards in space. A satellite in geosynchronous orbit located at 22,247 miles above the equator can accomplish this by rotating at just the same speed as our planet (see Figure 3-1). This is in sharp contrast to the early telecommunication vehicles which, in either low circular or elliptical orbits, were in view from earth stations for only limited periods, had to be tracked by complex, bulky equipment, and were able to relay messages for only short durations of time. Furthermore, since the launch of Syncom II, relatively small, geosynchronous earth receiving stations can be used. Each satellite can "see" 40% of the earth's surface and so, in theory, only three "super satellites" would be necessary (Figure 3-3) to link the entire globe. In practice, many more geosynchronous vehicles are rapidly populating the equatorial arc like a giant charm bracelet.

This satellite communication network is revolutionizing the transmission of information. In particular, the impact on television and radio broadcasting is profound. Before the advent of satellites, broadcasting depended on cables, microwave line-of-sight relays, or the distribution of videotapes to relay programming over long distances. Satellite broadcasts are now by far the most economical method for distances greater than approximately three hundred miles (although advanced fiber-optic cables could alter the picture). In addition, since

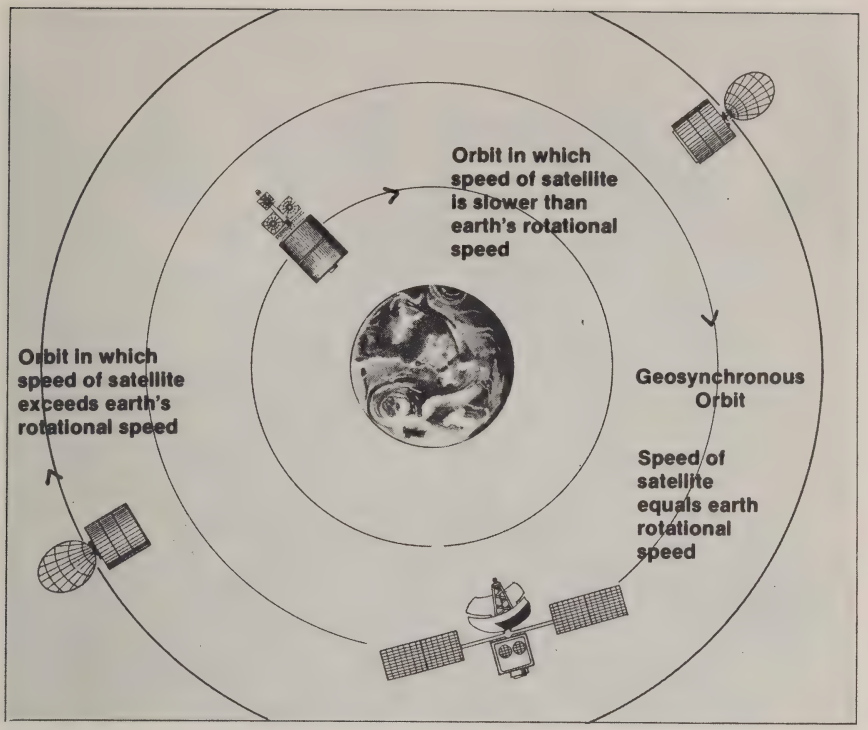

Orbit in which speed of satellite is slower than earth's rotational speed
Orbit in which speed of satellite exceeds earth's rotational speed
Geosynchronous Orbit
Speed of satellite equals earth rotational speed

Figure 3-1 The Geosynchronous Orbit. Satellites above or below this orbit at 22,300 miles over the equator will rotate more slowly or rapidly, respectively, than the speed of the earth below. Only satellites at the geosynchronous orbit will stay in the position relative to the earth below.

only one "relay station," the satellite, is necessary, many points can simultaneously receive the same broadcast. Also, since the signal is not transmitted, received, and retransmitted by many earthbound relay stations, broadcasts can be of much higher fidelity. Another advantage is that radio and television broadcasters are no longer limited to receive one program at a time by a single landline feed, but can now choose many shows to be recorded simultaneously for later use.

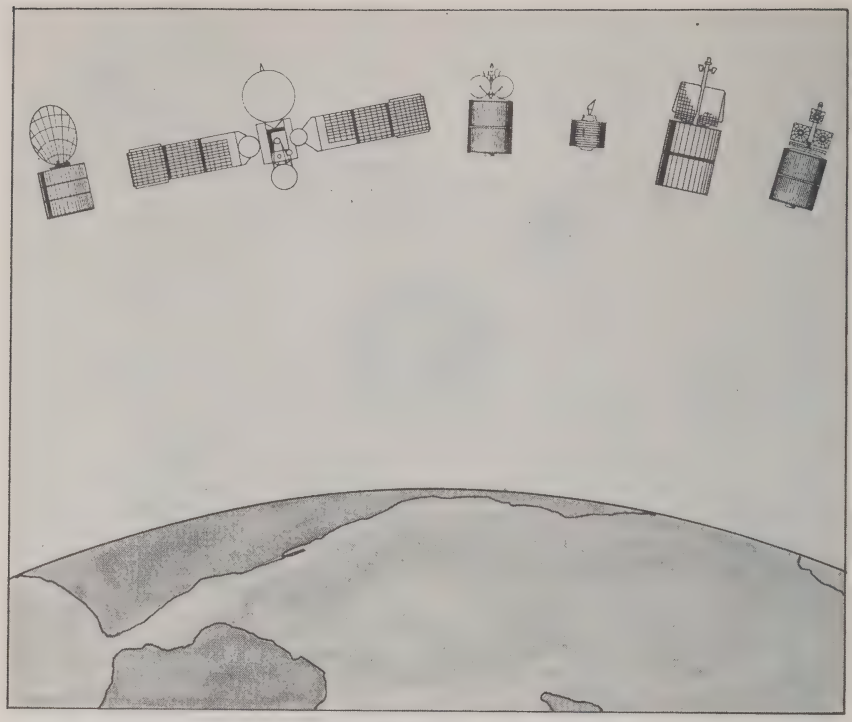


Figure 3-2 Geosynchronous Satellites. Satellites at the geosynchronous orbit encircle our globe above the equator.

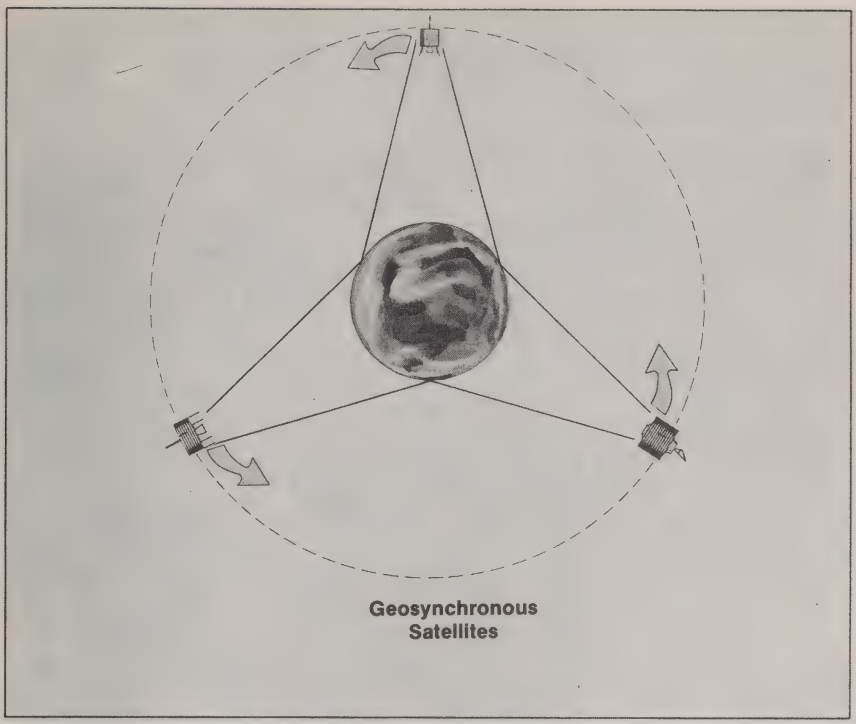


Figure 3-3 A Worldwide Communication System. In theory, only 3 geosynchronous satellites could serve the entire globe.

How do Satellites Work?

A telecommunication satellite is about the size of a car, and it receives and relays messages (Figure 3-4 through 3-7). Signals from earth uplink stations have powers of fractions of a millionth of a watt by the time they reach the satellite. In the heart of the communication vehicle, these signals are amplified many thousands of times, and the frequency is then lowered so that the powerful radio waves relayed earthward do not interfere with the original uplinked message. Satellite antennas send approximately a 2000- to 8000-watt signal (about the same power as a few 1000-watt light bulbs used for nighttime football games) into a well-defined beam to complete the circuit. All the power to carry out these electronic functions is provided by the sun's energy,

which is captured by arrays of solar cells. The overall quality of a telecommunication satellite depends both on how accurately receiving and sending antennas are pointing and on the signal-to-noise ratio of the downlinked message.

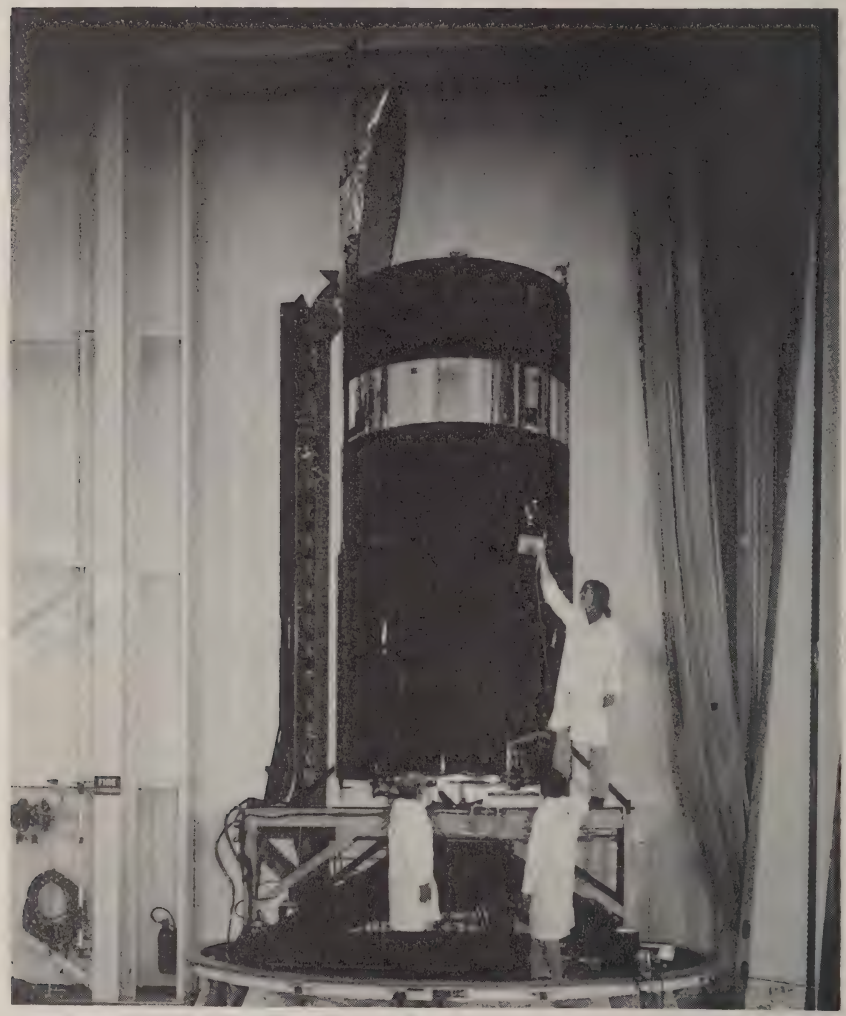


Figure 3-4 SBS Telecommunication Satellite. This vehicle is shown undergoing a pre-launch test at Hughes Aircraft Company in preparation for launch November 15, 1980, from Cape Canaveral, Florida. The first of a series of three, the satellite was built by Hughes Aircraft for Satellite Business Systems which is jointly owned by IBM, Comsat, and Aetna Life and Causalty. This relay provides secure voice, video teleconferencing, data and electronic mail services to U.S. businesses. The powerful satellite has two concentric cylindrical solar panels, which telescope in space from 9 feet to nearly 22 feet high, to double the spacecraft's solar-power generating capacity over that of many previous satellites. (Courtesy of Hughes Aircraft Company).

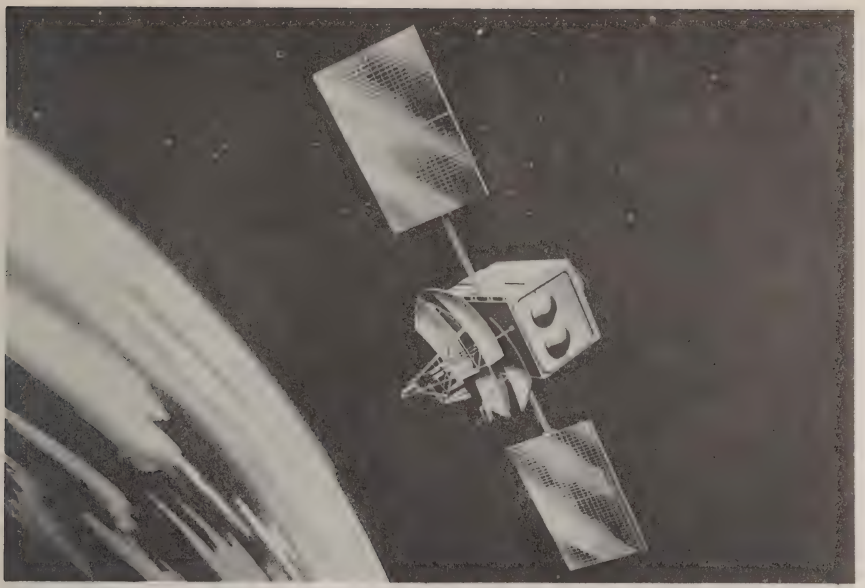


Figure 3-5 Satcom Satellite. The large wing-like structures are solar cells which provide on-board power. (Courtesy of RCA American Communications).

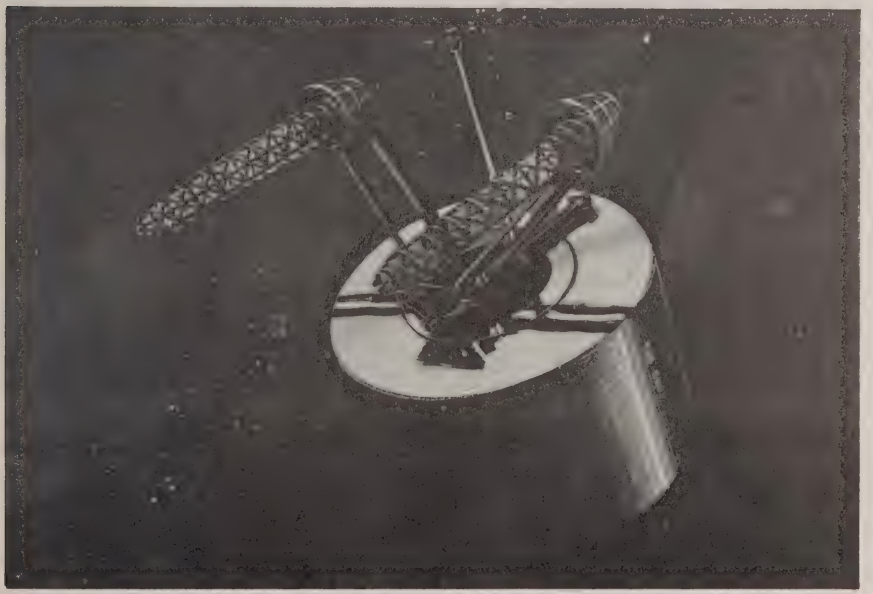


Figure 3-6 LEASAT Satellite. First of the "widebody" satellites, the LEASATs are designed to take maximum advantage of the Space Shuttle's capabilities. The satellites are positioned around the Earth to relay communication for the U.S. Navy and other military customers. Each vehicle is 14 feet in diameter and 20 feet high with antennas deployed. This size will make efficient use of the Space Shuttle's 15-foot diameter payload bay. (Courtesy of Hughes Aircraft Company).

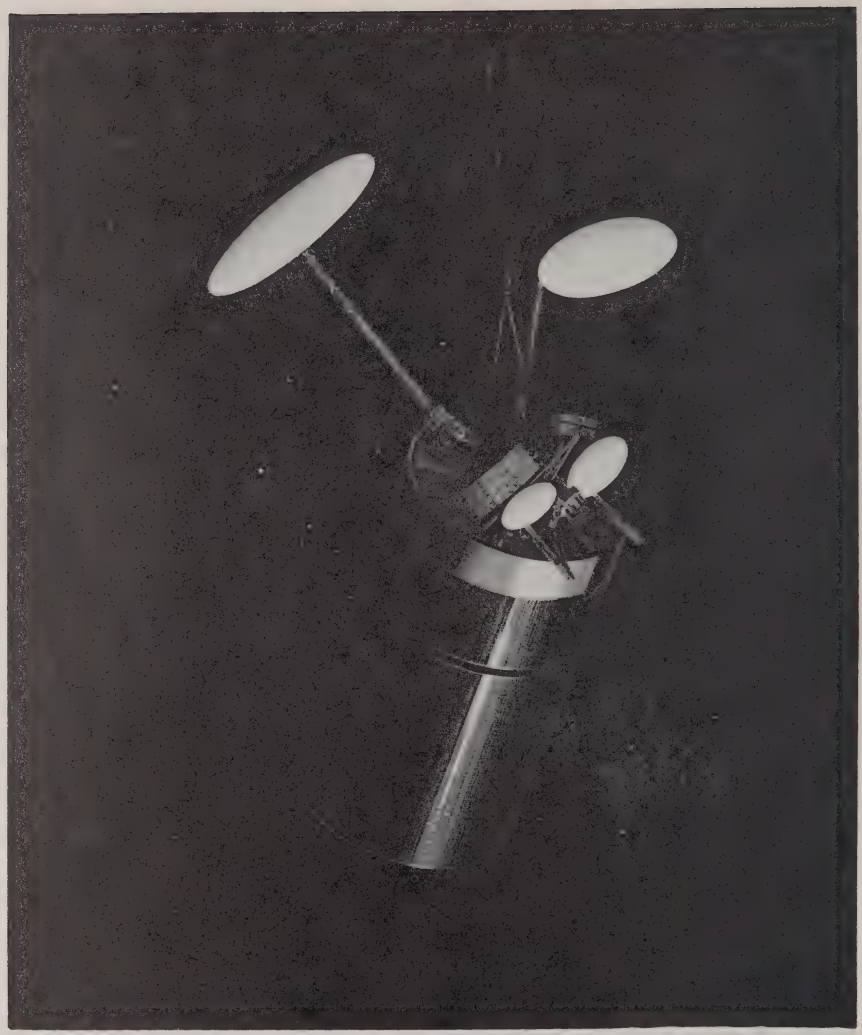


Figure 3-7 Intelsat VI. The next-generation Intelsat VI communication satellite stands nearly 39 feet high in space with its antenna unfolded and aft solar panel extended. Built by Hughes Aircraft Company for Intelsat, the spacecraft was the most massive civil vehicle ever launched (as of 1983). (Courtesy of Hughes Aircraft Company).

The number of television channels or other information carried by each satellite is related to its electronic design. The early Western Union vehicles such as Westar I and II could handle 12 television shows simultaneously; the RCA series of Satcom vehicles relayed 24 channels. How is the number of channels determined? First, uplinked messages are added to carrier waves in the band of frequencies from

5.925 to 6.425 gigahertz. After they are received in space, the satellite lowers the frequencies of these messages from earth to a band from 3.7 to 4.2 gigahertz, which has a bandwidth of ½ gigahertz, or 500 megahertz. Engineers who built the Western Union satellites divided this 500-megahertz band into twelve bands of 40-megahertz width each, which are separated from each other by 4-megahertz-wide protection regions to eliminate "crosstalk" between channels. Each of these channels is relayed by a device called a "transponder", and they are numbered from 1 to 12. Engineers working on the Satcom satellites used a clever technique to allow 24 channels to be managed. All the even channels are relayed by horizontally polarized radio waves, while all the odd ones are relayed by vertically polarized signals. Thus, transponder 6 has horizontal polarization, and transponder 7 has vertical polarization. In this 24-transponder system every channel has a 36-megahertz bandwidth with 4-megahertz-wide protection regions. As shown in Figure 3-8, the centers of the horizontally and vertically polarized bands are offset from each other for further security against

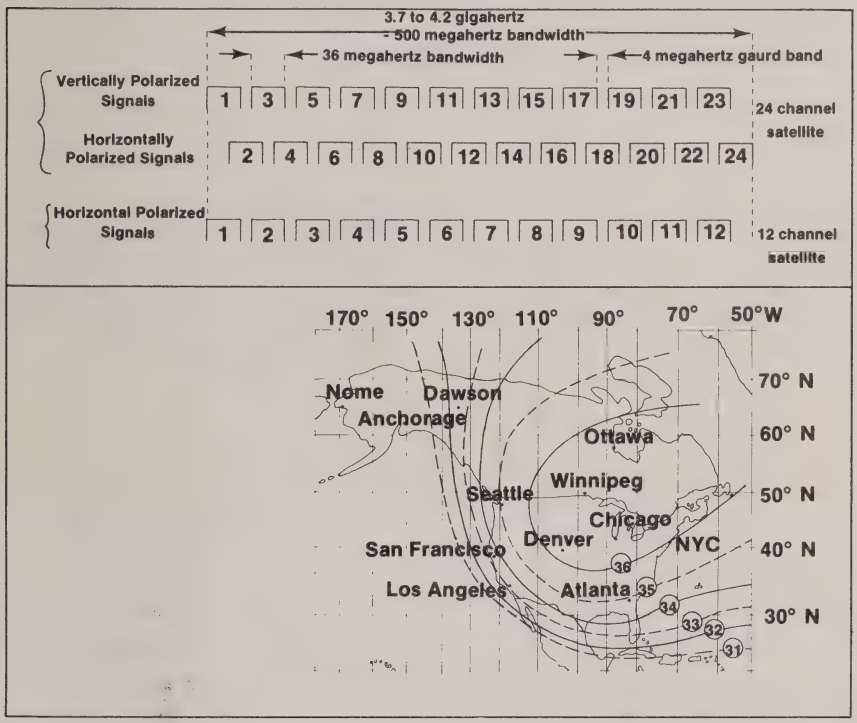
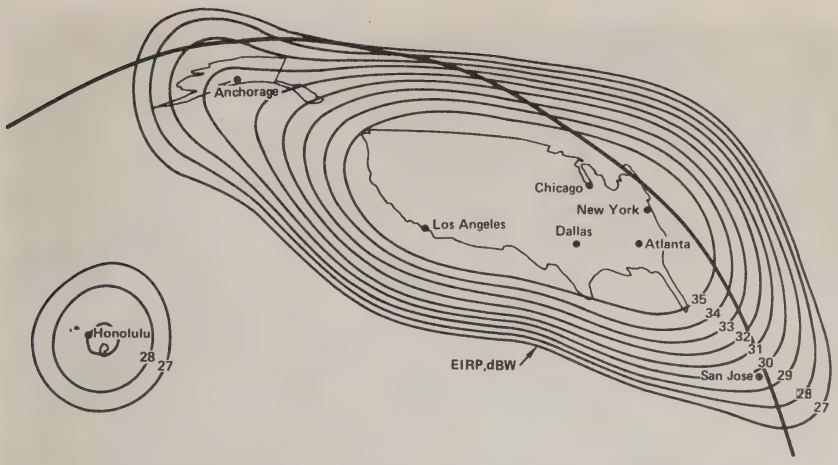


Figure 3-8 Satellite Downlink Frequency Plans. The sequential numbers refer to the transponder numbers. (Please see text for a more detailed explanation).

crosstalk. Thus, the downlinked beam is composed of carrier waves from each transponder, and any earth station can separate channels of the opposite polarizations as well as channels of the same polarization as any conventional television set would do.

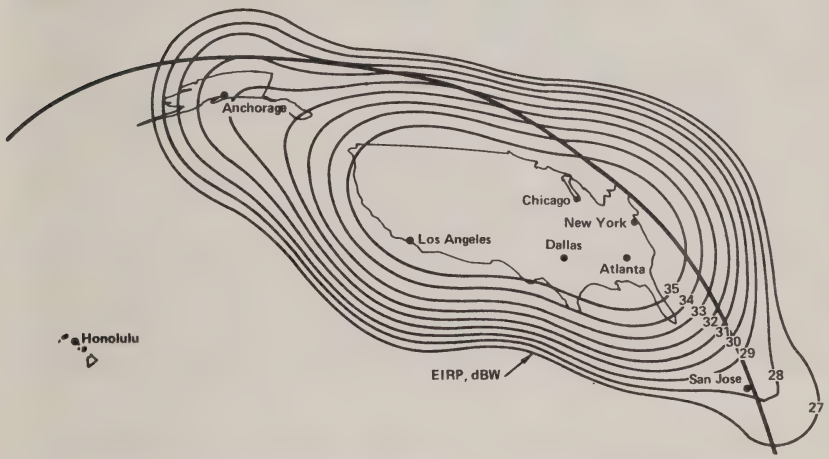
Many satellite designs have been developed as the number of vehicles has increased. The accompanying pictures in this chapter give an indication of how many different shapes these space relays have. The electronic designs also vary. Satellites, depending on their intended use, have a chosen number of transponders and often higher or lower frequency bands than the 6/4 gigahertz transmission regions. For example, Satellite Business Systems operates the 10-channel, SBS-2 vehicle in the 14/12 gigahertz mode in which signals are uplinked in a band from 13.7 to 14.2 gigahertz and downlinked at from 11.7 to 12.2 gigahertz. The use of transponders may also vary. While only one television broadcast may be carried, many phone or computer conversations can be relayed over one channel. Often a "sideband" carrier may be transmitted with a television signal to carry information such as radio on a single transponder. In fact, as more sophisticated digital codes are developed for relaying television broadcasts, two or more programs can be relayed over a single satellite channel.

The "footprint" of a satellite describes where the radiation goes and what the signal strength is in every direction (Figures 3-9 through 3-12). Footprint maps are provided with every communication satellite to allow earth receiving station designers to size antennas and other equipment. For example, lines of equal signal power are drawn on the footprint map for the Satcom III-R space vehicle. The EIRP (the effective isotropic radiated power), a common term in the satellite field, simply refers to these power levels. These numbers are expressed in decibels, a designation often used by communication engineers.



Satellite Radiated Power — 135°W Longitude
Horizontal Polarization

Figure 3-9a Galaxy I Footprint. The 12 transponders having vertical polarization provide a maximumn of 35 decibels of power. (Courtesy of Hughes Communiccations, Inc.).



Satellite Radiated Power — 135°W Longitude
Vertical Polarization

Figure 3-9b Galaxy I Footprint. The 12 transponders with horizontal polarization include Hawaii in addition to the continental United States in their footprint. (Courtesy of Hughes Communication, Inc.).

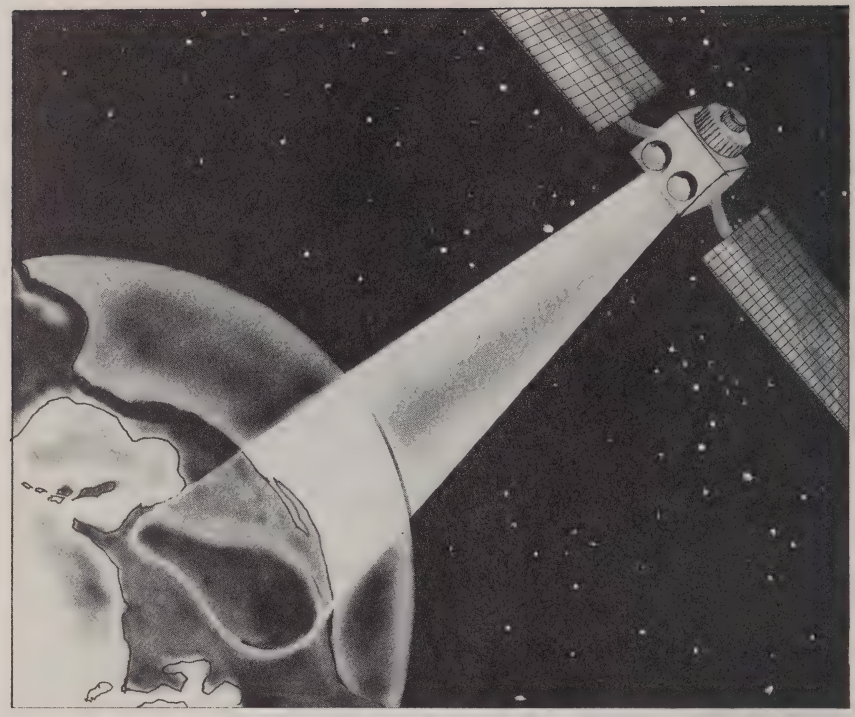


Figure 3-10 Satellite Footprint. This satellite serves approximately half of the North American continent.

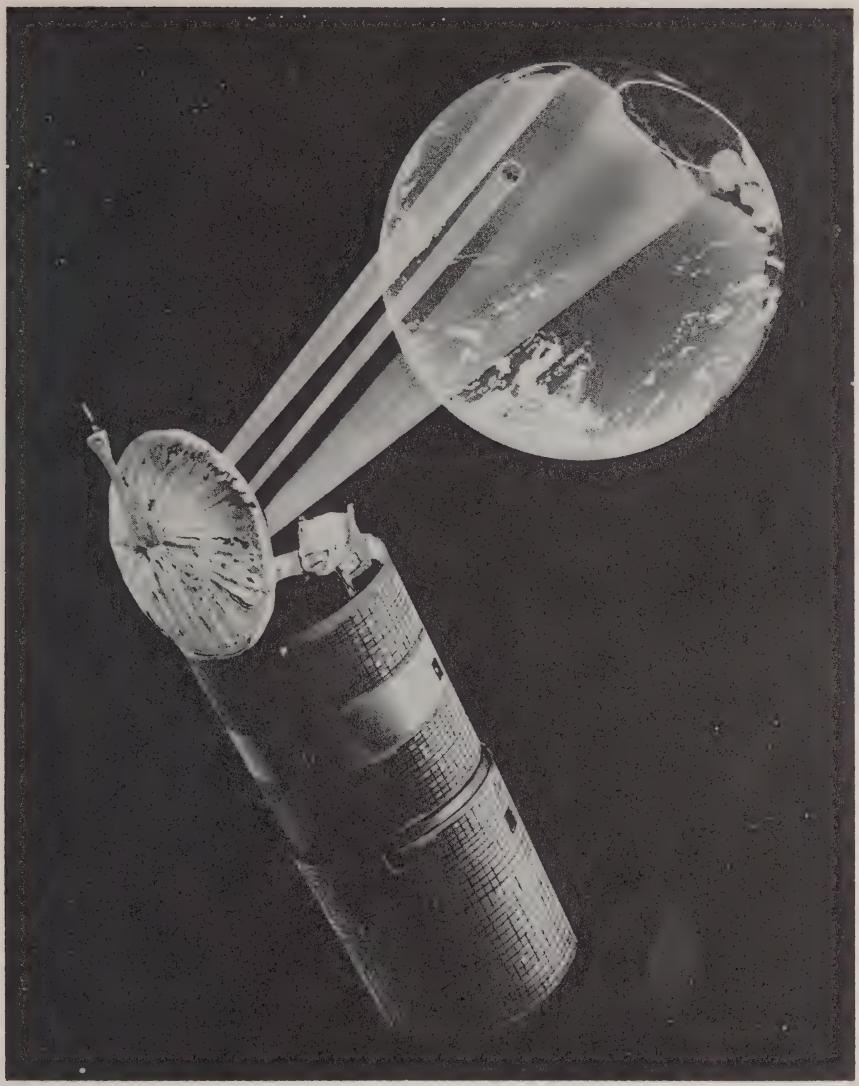


Figure 3-11 Galaxy Satellite. The three Galaxy satellites, built by Hughes Aircraft Company, offer communication services to business users. Each satellite has 24 transponders all of which are available for purchase for the lifetime of the vehicle. (Courtesy of Hughes Aircraft Company).

Figure 3-12 Westar IV and V Satellites. These satellites built by Hughes Aircraft Company have 24 transponders. The solar array generates 800 watts of power over a ten-year lifetime. (Courtesy of Hughes Aircraft Company).

Because modern amplifiers can easily increase the strength of a signal a hundred thousand times, the decibel scale was developed to describe such enormous changes in much smaller numbers. Table 3-1 below shows how this scale is used. A useful fact to remember is that a small change in decibels means a relatively much larger change in power levels.

The Decibel Notation

Number of Decibels	Relative Increase in Power
1	1.26
3	2
5	3.2
10	10
20	100
30	1,000
50	100,000
100	10,000,000,000

TABLE 3-1

Footprint maps that have small changes in decibel levels show how widely signal power levels actually change. The signal strength on any footprint map is always highest right along the direction an antenna is aimed. For example, the power received in Anchorage, Alaska, at 33 decibels is really half of that received in Denver, Colorado, at 36 decibels because there is a 3 decibel difference. Satellites broadcasting to a more limited geographical region would have a footprint covering a smaller area. They would have a much higher EIRP than would a satellite broadcasting nationally, because approximately the same power would be more concentrated. Consequently, because footprint maps are determined by the shape and the orientation of a downlink antenna and the power that it transmits, designers of antennas play a very important role.

When a signal leaves the downlink antenna it spreads out in a cone-like beam as it travels to the earth below. This weakening in power is called the "free space path loss." As the distance between an earth station and a telecommunication satellite increases, these free space path losses become even greater. To illustrate, a message would be weaker in Minnesota than in Florida if equal power had been directed to both locations, since Florida is closer to the equator. Since Florida is also further off the main axis of a downlink antenna directed towards the entire country, it also has lower EIRP. It is important to understand that EIRP refers to the power levels at the satellite directed towards each geographic location and not to the actual power received on earth.

Some of this signal is also lost when it passes through molecules of the atmosphere and is absorbed by them. Water vapor is the main culprit in the attenuation of downlinked signals. In fact, during a severe rainstorm, the power received on the surface of the earth can be reduced by as much as 50%.

The free space path loss and atmospheric absorption explain why a signal of 2000 watts leaving a typical satellite is received on earth at a strength of less than approximately one tenth of a billionth of a billionth of a watt!

Satellite Launching and Maintenance

The excellence of our satellite communication system depends on launching durable space vehicles into stable geosynchronous orbits. Since the launch of Sputnik I in 1957, man has been able to lift heavier and more sophisticated payloads into orbit. During the 1960's booster rockets were inadequate to position a satellite directly into geosynchronous orbit. As a result, extra rockets in the body of a telecommunication vehicle were used for repositioning it from its initial low circular orbit into its final geosynchronous position. The engine and fuel of the satellite then accounted for nearly half of its total weight.

Today, a similar technique for boosting a satellite into space is used even though current communication vehicles have greater masses and can be lifted into space by more powerful craft. The earlier Thor-Delta launch rockets have been replaced by stronger boosters such as the Delta-2914, the Delta-3912, and the Atlas Centaur. For example, on September 24, 1981, NASA launched the SBS-2 (Satellite Business Systems-2) into a circular orbit at 19,236 nautical miles. This satellite then drifted into its correct orbital slot at a rate of 2.87 degrees east per day, and finally it was boosted into its slightly higher geosynchronous orbit.

In coming years many satellites will be boosted into position by the Space Shuttle so that heavier, more powerful vehicles can be recruited into service. In 1983, a number of satellites including the Canadian Anik C2 and the Indonesian Palapa B were launched on the Shuttle. Also, Comsat's subsidiary, the STV Corporation, has already requested space on two shuttle flights in order to launch its first two higher-frequency, direct broadcast satellites in mid to late 1985.

Geosynchronous satellites would remain stationary forever above a chosen location over the equator if there were no extra gravitational forces from the sun and the moon, if solar winds did not sweep past our globe, and if the earth was perfectly round. These forces cause any satellite to drift slowly away from its assigned location. There is, however, a "zero-pull" location at approximately 104.5°W. at which all

these forces balance so that a space vehicle will remain stationary. The Canadian satellite Anik I is located at 104°W. and is the closest western-hemisphere satellite near this point. A second "zero-pull" location is found on the exact opposite side of the globe. All satellites to the west of 104.5°W. will drift towards the east, and those located to the east of this point will drift westward.

Consequently, ground controllers are required to adjust the position of a satellite periodically to counteract this tendency towards drifting. All satellites are equipped with small hydrazine gas charged "thrusters" that are fired whenever necessary.

Satellite antennas and solar cell arrays must also be periodically realigned with their targets. In order to relay a beam having a width of approximately 1.25° towards a chosen location on the earth, the antenna must be accurately pointed within 0.2°. This is very important because most satellites, even when accurately positioned, move in a small figure-eight pattern, usually about 15 miles across. Even this very small movement can impair reception of signals on earth. In some satellites the solar cell arrays must also be accurately pointed towards the sun so that they will provide as much power as possible. Satellites are therefore aligned by the spinning of their whole body in order to create a stabilizing gyroscopic effect similar to those forces that keep a rapidly spinning top upright. The improved stability of present-day vehicles permits the use of larger antennas capable of focusing higher-power microwave beams and having larger solar cell arrays that increase the satellite's power.

Satellites do not live forever. Their life expectancy is determined by how long adequate power and stability can be maintained. The repositioning rockets usually run out of hydrazine gas after ten years. Also, solar cells are constantly bombarded with micrometeorites and cosmic rays that slowly wear them out. Either a 30% reduction in the power of the solar cells or expiration of the hydrazine fuel is a signal to retire a satellite from active duty. When ground controllers put a satellite to rest, it is boosted into a slightly higher non-geosynchronous orbit or allowed to drift slowly to one of the two "zero-pull" points on the equatorial ring. Some "dead" vehicles are now clustered at such a point 22,300 miles above the International Date Line. This satellite burial ground could be crowded in decades to come, and may remain as a reminder of our technological civilization for future archeologists or even space travellers.

How Much Do Satellites Cost?

The total cost of a satellite is determined by the expenses of building, launching, and operating each vehicle. In the early 1980's the cost of building a telecommunication satellite ranged from $25 to $140 million depending on its complexity. For example, the RCA Corporation is earning in excess of $100 million building 3 G-Star vehicles for GTE Satellite Corporation and a similar amount constructing 3 Spacenet outposts for Southern Pacific Communications Company. Alascom, Incorporated purchased RCA Americom's Satcom V for $29 million, while Intelsat paid $74 million to Ford Aerospace for construction of three Intelsat V-A satellites. Hughes Aircraft has contracted to build five sophisticated Intelsat VI vehicles for $700 million at a cost of $140 million per satellite.

Costs to launch a telecommunication vehicle ranged from $16 million to $80 million in the early 1980's. These costs depend upon the size of the satellite as well as upon the organization chosen to launch it. NASA is competing with Arianspace, a joint venture of several European space companies, which launches vehicles from Kourou, French Guiana. For example, Intelsat is spending about $154 million for one NASA-Atlas Centaur and two Arianspace Ariane-3 vehicles required for launching three Intelsat V/V-A satellites, while Western Union Telegraph Company paid $22 million to Arianspace for launching its Westar VI vehicle. For a total of $76 million Intelsat V,F-4 was lifted into orbit from Cape Canaveral aboard an Atlas-Centaur booster and transferred into geosynchronous orbit.

Because of these high launch fees and the potential for lucrative profits other companies are competing for this business. Space Services of Houston and GCH of Sunnyville, California, have planned to charge between $3 million and $5 million per launch. Although their first attempted launch with the 53-foot Percheron Rocket ended with an explosion, a second small, test vehicle, the Conestoga, was successfully launched in 1982. Another private venture, Otrag, has considered Argentina as a possible launch site. A third enterprise, the Satellite Broadcasting Company, a joint effort of British Aerospace and N.M. Rothschild and Sons, Ltd., plan to construct, launch, and operate direct broadcast television satellites to serve the United Kingdom.

Clearly, building and launching a telecommunication satellite is a very costly venture. However, over the past 20 years launching technology has substantially improved so that the cost per pound of orbiting a communication vehicle has dropped dramatically (see Table 3-2). During the same time, improvements in the capacity and sophistication of electronic equipment have allowed the costs per telecommuni-

cation channel to drop even more rapidly (see Table 3-3). The cost per voice channel is calculated by adding the costs for building and launching a satellite, dividing by the number of voice channels that can be transmitted, and then adjusting for the expected satellite lifetime. A projected cost for a large-scale domestic communication satellite launched by the Space Shuttle is less than $20 per voice channel. This is an amazing one hundreth of the same cost for Intelsat I, Early Bird!

Cost per Pound of Satellite versus Time

Satellite	Year of Launch	Cost ($ per pound)
Intelsat I	1965	54,117
Intelsat II	1967	23,958
Intelsat III	1968	18,633
Intelsat IV	1971	10,342
Intelsat V	1980	8,964

Costs of Satellite Communication Channels

Before the advent of satellites, services provided by cables and later by line-of-sight microwave relays were expensive. For example, in the 1960's, AT&T charged users of their New-York-to-Los-Angeles video circuit $2809 per hour. In 1974 this rate was lowered to $1832 per hour when the Western Union Telegraph Company introduced a comparable service via satellite for only $715 per hour. By 1981 the most expensive prime-time rate obtainable was $400 per hour.

Even so, until the late 1970's the demand for transponder time was low, and the pioneers had ready access to satellite relays. During 1976 the regular per-channel charge for video transponder time on a full-time, 10 hour per day basis offered by RCA was $60,000 per month, or approximately $200 per hour. In late 1979 time could be leased on one Comstar II transponder for $70,000 per month. By 1981 prices had risen even further. AT&T could lease transponder time on Comstar D-2 for $1,664,700 per year, or almost $139,000 per month. In 1982 the American Hospital Video Network leased a higher-frequency transponder on the STS-2 satellite for relaying medical education and news for a whopping $3.2 million per year, or almost $270,000 per month. Even though the rising demand for transponders over this period of

time had caused a sharp increase in costs, the real costs per channel fell by 18 times from 1965 to 1980. During this period the consumer price nearly doubled, but the costs per channel fell by 9 times.

Full-time users of satellite communication circuits have options other than leasing time. In the most extreme cases, an organization will actually purchase and launch a communication vehicle. Owners of satellites have also been selling lifetime ownerships of a complete circuit. Such sales offer the owners a faster recovery of their money in times of increasing costs and high interest rates. Users are also protected by being guaranteed both predictable costs and transponder time. As a result, transponders have been purchased on the Galaxy I, Spacenet I, and Satcom IV satellites.

Users of Satellite Communication Circuits

Users of satellite communication systems can be grouped into five general categories. The satellite common carriers own and operate their own satellite communication systems. These companies include AT&T, Satellite Business Systems, RCA, Western Union, American Satellite Company, Southern Pacific Communications, and Hughes Aerospace. A second group buys full-time use of one or more circuits from the owners of satellites for their own use. Third are those businesses that buy blocks of satellite time for resale to others requiring only part-time use of circuits. Companies catering to broadcast television, such as Wold Communications and Hughes TV, have expanded and now provide business communication services. Fourth, network coordinators perform a different function by arranging all the necessary ground equipment and facilities as well as satellite time for one-time events such as teleconferencing. The oldest group performing these services, the Public Service Satellite Consortium, has been joined by a host of competitors. The fifth category includes all the systems-hardware vendors who supply complete systems for communicating via satellite. Part of this group are the many hundreds of component-hardware vendors supplying those who wish to piece together their own communication systems.

Communication Satellite Guide

As a result of a strong demand for transponder time, the FCC has been bombarded with requests for operating domestic communication satellites. In late 1980 this regulatory arm of the American government responded by expanding the arc in which communication relays were allowed to be positioned from 70°W. to 135°W. to a larger 55°W. to 143°W. This action indicated the FCC's new policy of allowing the number of satellites to increase. By late 1983 the FCC had processed

requests to launch 53 satellites in addition to the 38 American vehicles already in orbit. Similarly, Intelsat and the International Telecommunications Union have been responsible for managing requests from its member nations, so that by 1982 more than 100 communication vehicles were in orbit.

Table 3-4a and b outline the operating and future domestic communication satellites. Although Satcom III-R, Satcom IV, and Westar IV are the three key satellites devoted to video broadcasting in the United States, the bulk of the in-orbit communication vehicles are and will be used for relaying other types of information. Also, these tables do not list military and international satellites, whose numbers are too many to include here. A brief sample of such satellites demonstrates the activity in these areas. The U.S. Navy operates five FleetSatCom satellites to interconnect its worldwide fleet, while the international marine communication group, Inmarsat, uses five of the Intelsat V vehicles positioned over the Indian and Atlantic Ocean for marine communication. In June 1981 both the Indian Apple satellite and the meterological-survey Meteosat satellite were launched by the Ariane organization. Arabsat, a 22-nation Arabian group, operates a regional satellite communication system carrying voice, telex, television, and other information via Ford-built satellites. The Japanese Sakura CS, CS-2a, and CS-2b vehicles are being used to test higher-frequency transmissions, while the Canadian Anik series of outposts are linking one of the first direct broadcast scrambled television systems for remote locations.

Cost per Communication Channel versus Time

Satellite	Year of Launch Cost	($ per Channel)
Intelsat I	1965	20,000
Intelsat IV	1971	750
Westar	1974	300
Intelsat V	1979	200

TABLE 3-3

Domestic Communications Satellites

Satellite Name	Owner	Manufacturer	Launch Date	Orbital Position (°West)	Frequency Band(s) (GHz)	Lifetime (Yrs)	Number of Transponders
Westar I	ASC and Western Union a	Hughes Aircraft	4/74	99	C	7	12
Westar II	"	"	1974	79	C	7	12
Westar III	"	"	1979	91	C	7	12
Westar IV	"	"	2/82	99	C	10	24
Westar V	"	"	6/82	123	C	10	24
Westar VI	"	"	1984	78.5	C	10	24
Westar VII	"	"	1984	86	C	10	24
Westar VIII	"	"	1985	98.5	C		24
Galaxy I	Hughes Aircraft	Hughes Aircraft b	6/83	134	C	9	18 (6 in reserve)
Galaxy II	"	"	9/83	74	C	9	18
Galaxy III	"	"	6/84	93.5	C	9	18
Comstar D1	Comsat c General	Hughes Aircraft	5/76	95.9	C	7	24
Comstar D2	"	"	76	95	C	7	24
Comstar D3	"	"	78	87	C	7	24
Comstar D4	"	"	12/81	127	C	7	24
Satcom I	RCA	RCA	12/75	119	C	7	24
Satcom I-R	"	"	4/83	139	C	10	24
Satcom II	"	"	11/76	119	C	8	24
Satcom II-R	"	"	3/83	72	C	10	24

a) American Satellite Corporation (20%) and Western Unioin Telegraph Company (80%). ASC is a joint venture of Continental Telephone of Atlanta and Fairchild Industries.

b) These satellites are part of the Hughes HS 376 family which includes the SBS, Westar IV to VI, Anik C and D, Telstar 3, and Polapa B Series.

c) Comstar D-1 and Comstar D-2, located closely together, operate as a composite satellite.

d) SBS is an abbreviation for Satellite Business Systems, a joint venture of IBM, Comsat, and Aetna Life & Casualty.

e) Southern Pacific Communications, a private venture like ASC and SBS.

f) U.S. Satellite Systems, Inc.

Table 3-4a

Table 3-4a Domestic Communications Satellites (continued)

Satellite Name	Owner	Manufacturer	Launch Date	Orbital Position (°West)	Frequency Band(s)	Lifetime (Yrs)	Number of Transponders
Satcom III-R	RCA	RCA	11/81	131	C	8	24
Satcom IV	"	"	1/82	83.5	C	8	24
Satcom VI	"	"	1985	67	C	9	24
Satcom K-I	"	"	1982	77	Ku		24
Satcom K-2	"	"	1985	87	Ku		24
Satcom K-3	"	"	1985	126	Ku		24
Gstar I	GTE Sat. Corp.	RCA	1984	103	Ku		16
Gstar II	"	"	1984	105	Ku		16
Gstar III	"	"	Spare	TBD	Ku		16
Telstar-1	AT&T		7/62	95	C	7	24
Telstar-2	"		5/63	87	C	7	24
Telstar-301	"		7/83	96	C	10	24
Telstar-302	"		1984	76	C	10	24
Telstar-303	"		1985	88.5	C	10	24
Telstar-304	"		1985	125	C	10	24
ASC1	ASC	ASC	1985	128	C,Ku	7.5	12
ASC2	"	"	1986	81	C,Ku	7.5	6
ASC3	"	"			Ku	7.5	6
SBS-1	SBS [d]	Hughes Aircraft	11/80	99	Ku	7	10
SBS-2	"	"	9/81	97	Ku	7	10
SBS-3	"	"	9/82	95	Ku	7	10
SBS-4	"	"	1984	89	Ku	7	10
SBS-5	"	"	1986	124	Ku		10
Spacenet 1	SPC [e]		5/84	122	C,Ku		
Spacenet 2	"		1984	69	C,Ku		
Spacenet 3	"		1985	91	C,Ku		
USAT-1	USSS [f]		1985	85	Ku		10
USAT-2	"		1986	120	Ku		10

American Direct Broadcasting Satellites
(Planned in 1982)

Name	Operator	Launch Date	Orbital Position (°West)	Bandwidth (GHz)	Life (Years)	Number of Transponders per Satellite
Westar	Focus	1983+	91	225	10	6
CBS	CBS, Inc.		83	27	7	3
DBSC	DBC Corp.	1985+	103 123,143	22.5 22.5	7 7	6 8
GSC	Graphic Scanning Corp.	1986	115,143	18	7	2
RCA	RCA		110,125 140,155	25,72	7	6
STC	STC Corp. (Comsat)	1985+	115,135 155,175	16	7	3
USSB	Hubbard Broadcasting		115,135	16	-	6
VSS	Video Satellite Systems		115,135 155,175	18	8	2
WU	Western Union		80,100 120,140	16	7	4

Table 3-4b

All satellite transponders, except for the Westar, were expected to operate on the 17.3 to 17.8 gigahertz uplink bands and the 12.2 to 12.7 gigahertz downlink band. The exception was expected to operate at 14 to 14.5 Ghz (uplink) and 11.7 to 12.2 Ghz (downlink).

4. MESSAGES FROM THE SKY
The Earth Station

Earth stations have become a prominent sign of our era. Large dish-shaped antennas are seen at hotels and bars, at television stations, and in the most remote rural areas. Although many people realize that antennas are the first part of satellite receiving stations, they do not always completely understand these innovations. Many questions arise. How many channels can an earth station receive? Why do these dishes have to be so large and expensive? Is a square dish better than a round one? Can one be built by a "do-it-yourselfer" for less than $1000? In a few years, will small 3-foot dishes be available that can be mounted in an attic? Does an antenna have to be mounted as high as possible just like a conventional one for receiving distant broadcast stations? Will prices continue to fall? Is it all legal? Is it necessary to buy a special television or other equipment to see the satellite television programs?

An earth station detects the minute signal received from a telecommunication satellite (Figure 4-1). Most dish antennas focus on one satellite at a time and concentrate these faint signals before funneling them into a device called a "feedhorn." The feedhorn then directs the microwave signal into a small, box-like low noise amplifier, which further increases its power many thousands of times. Afterwards, the signals are fed via cable lines into an in-door receiver, and following this into a modulator, which processes the message into a form that can be understood by any television set. Microwave signals weaker than a tenth of a billionth of a billionth of a watt can carry vast amounts of information that can be detected and understood. Modern science has truly achieved wonders.

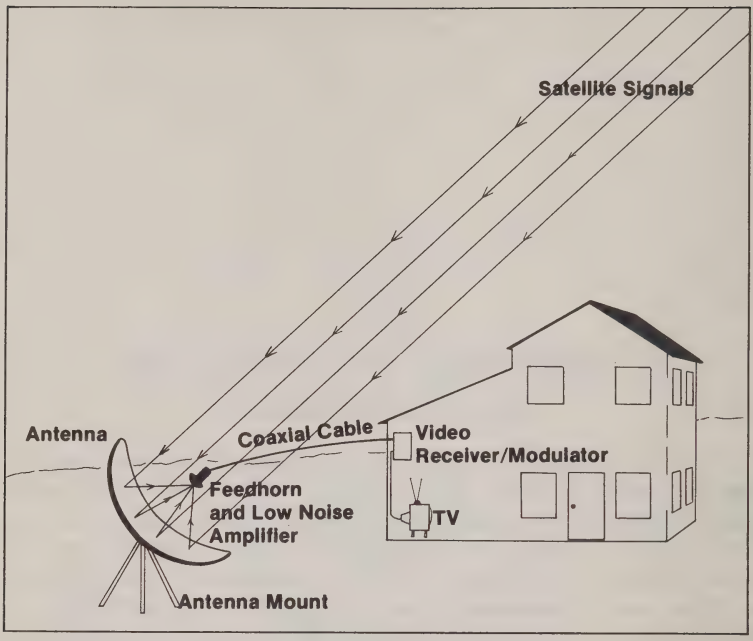


Figure 4-1 Typical TVRO Station. This includes an antenna and its mount, a feedhorn, a low noise amplifier, and a coaxial cable line to a video receiver and modulator.

The Antenna

An antenna, often simply called a "dish," must be of adequate size and quality to capture and sufficiently concentrate the faint signal from a distant satellite. It must also be able to aim at these microwave signals accurately so that other messages and noise from unwanted terrestrial and satellite sources are hardly detected. The dish, about 40 to 50% of the cost of a complete earth station, should be durable and maintain its accuracy for years.

Varieties of Antennas

Most microwave antennas used today in satellite earth receiving stations are built with combinations of circular or parabolic surfaces, which are familiar geometrical shapes originally discovered by the ancient Greeks. Any radio waves reflected off these surfaces will be concentrated to a point or to a series of points called "focal points."

Even the original horn-shaped Telstar earth station, which weighed many tons and had to be rotated to follow its targeted satellite as it raced across the sky, had a parabolic cross-section.

Antennas can be grouped into two broad categories: single-beam and multiple-beam antennas. A single-beam antenna reflects signals from a satellite to a single feedhorn. In order to target a second satellite, the whole body of the antenna, with the feedhorn fixed in position, has to be moved. Multiple-beam antennas use a common reflector surface with one moveable feedhorn or multiple feedhorns so that more than one satellite can be simultaneously detected.

The most familiar single-beam antenna, the prime-focus parabola, theoretically concentrates all incoming signals directed parallel to its axis to a single point. Any signals travelling from a direction other than that of the target will be reflected away from the focal point (see Figure 4-2 and 4-3). In practice, this dish will not behave as a perfect prime-focus parabola for two reasons. First, the equipment mounted at the antenna focus is spread around the focal point so that it will intercept some radiation from directions slightly off the target. Also, since the surface of an antenna is never a perfect parabolic shape, irregularities cause errors in reflection so that some non-targeted signals are inadvertently detected and some targeted signals pass by unobserved. The quality of the prime-focus and all other antennas is determined by how closely the surface of a dish approximates its designed shape.

A prime-focus antenna can be cut into any convenient shape. Even if a round 15-foot dish had its corners trimmed so that it became a square measuring 9 feet on each side, it would still have a parabolic surface to direct the intercepted radiation to a single point. The main difference between this dish before and after trimming would be in the surface areas. Thus, a 9-foot square antenna having an 81-square-foot cross-section would intercept slightly more signal than would a 10-foot round dish having a 78.5 square foot cross-section.

A second similar antenna, the Cassegrain, is also a parabolic dish, which reflects the signal a second time at the focal point to a location behind the dish (see Figure 4-2 and 4-4). The reflector at the focus is called a "parabolic subreflector". This type of antenna is usually more expensive than the ordinary prime-focus dish, but in some situations, such as when it is used in very hot climates, it performs more effectively.

There are other less familiar types of single-focus antennas. The horn reflector antenna, shaped like a horn (Figure 4-5), sends intercepted signals entering via a large aperture down the reflective body of

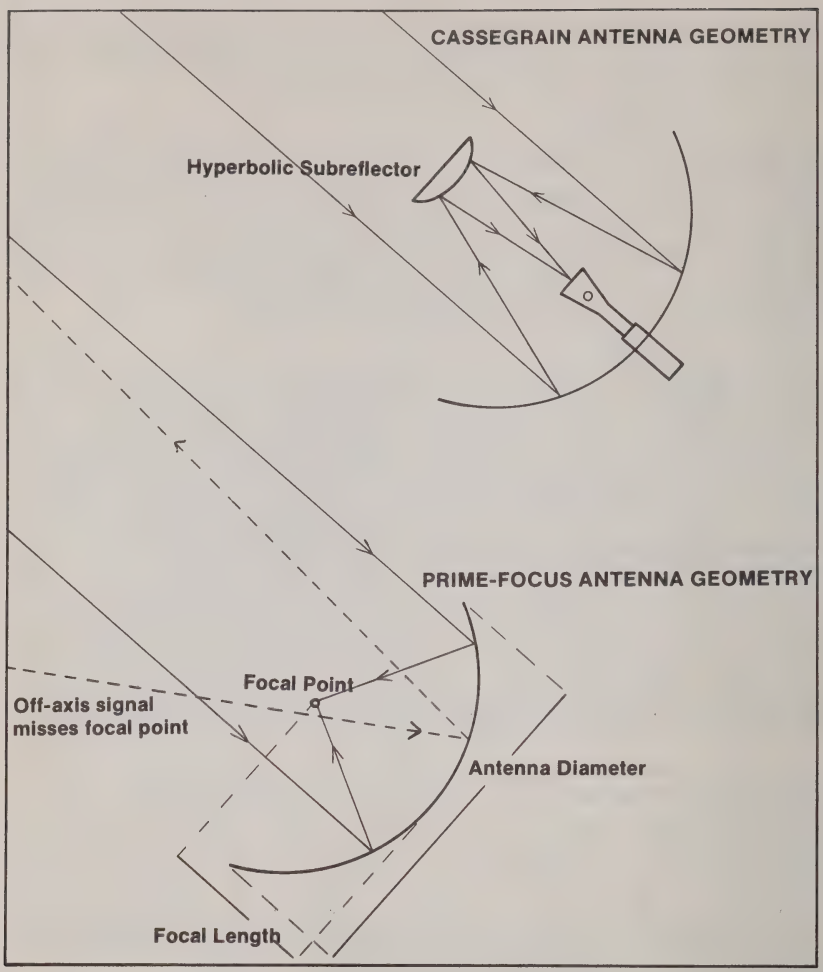


Figure 4-2 Prime-focus and Cassegrain Antenna Geometry. Signals are reflected as indicated.

Figure 4-3 A Prime-focus Antenna. This 5-meter M/A COM antenna is molded from fiberglass. (Courtesy of M/A COM, Inc.).

Figure 4-4 A Cassegrain Antenna. This M/A COM 5-meter dish is composed of fiberglass. (Courtesy of M/A COM, Inc.).

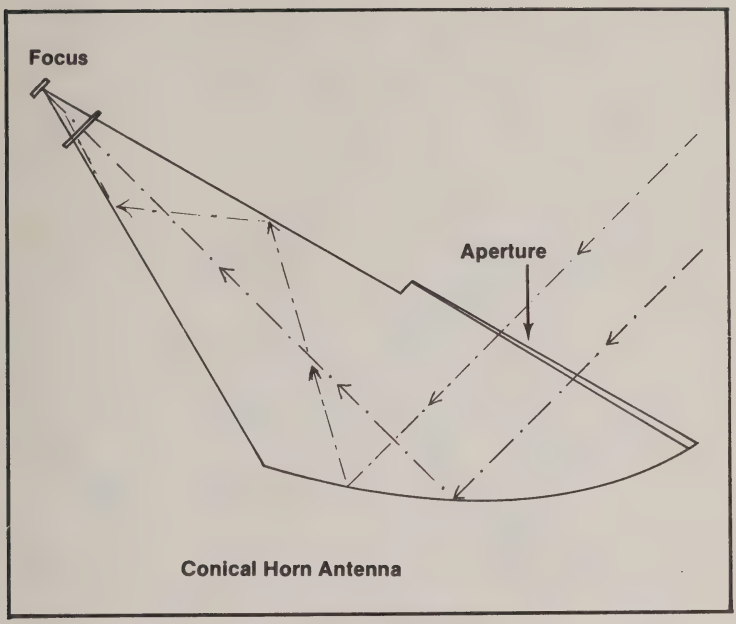


Figure 4-5 Conical Horn Antenna.

the horn to a focus. The whole body of the horn performs the same function as the feedhorn does for a prime-focus or Cassegrain antenna. Also, both the Cassegrain and the prime-focus antenna can be used in the offset-fed configuration. This setup has the advantage that the aperture or the dish is not blocked by the feedhorn and the low noise amplifier

Multiple-focus antennas have been developed recently to allow more than one satellite to be detected from a fixed mounting position. In contrast, a prime-focus dish has to be repositioned to receive signals from each satellite. Cable companies and other operators of TVROs have the option to own either two or more conventional antennas or one multiple-focus antenna if they wish to simultaneously view transmissions from two or more antennas. Today, as the number of satellites increases and as land becomes more and more expensive, a multiple-focus dish can be advantageous.

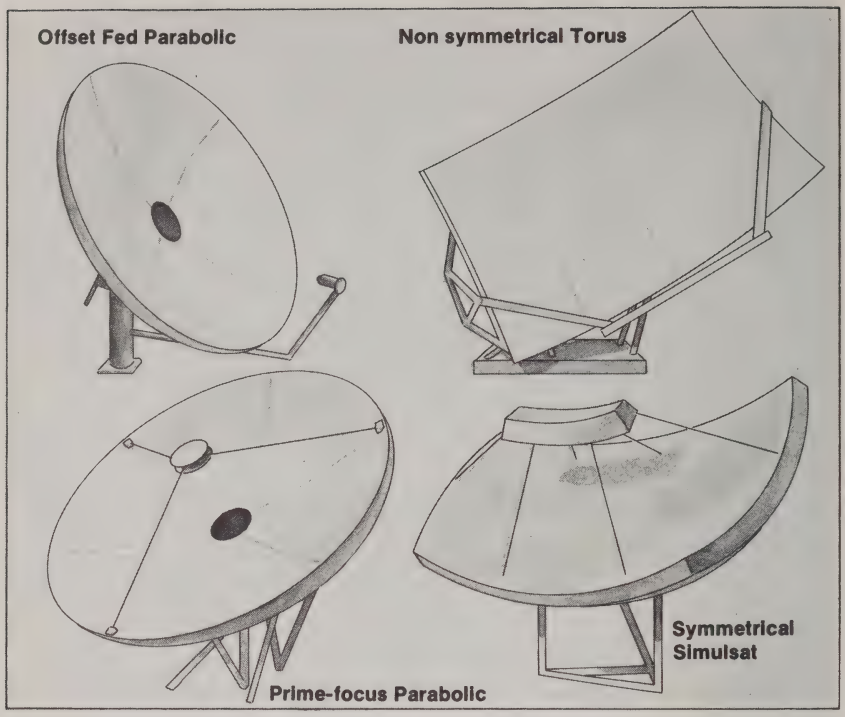


Figure 4-6 Multiple-focus Antennas and Prime-focus Parabola.

The commonly encountered multiple-focus antennas incorporate variations of spherical and parabolic surfaces. In all cases, these dishes are aimed at the arc of satellites, and the reflected signals from each space vehicle are focused to a series of feedhorns. To illustrate, the Simulsat antenna is a rectangular section of a sphere with feedhorns mounted in a long box at the focal line. It can simultaneously detect up to twenty satellites within a 57° arc. These multiple-focus devices all have their feed offset from their central axis. In the case of

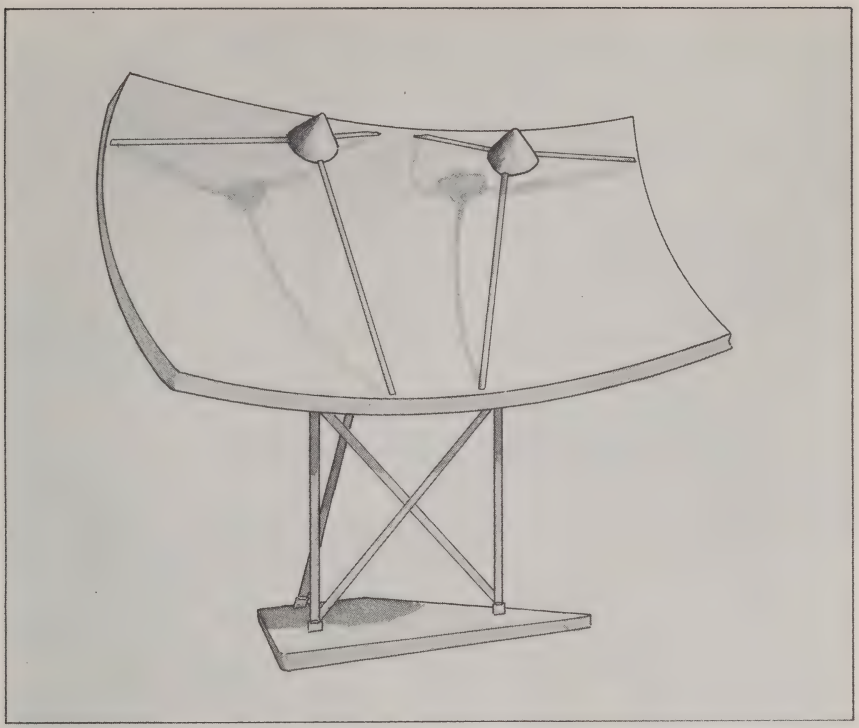


Figure 4-7 Multiple-focus Antenna. Two feedhorns each detect satellite messages from different points on the geosynchronous arc.

the Simulsat dish, the feed is offset along the arc of satellites. The Torus antenna, which is a dual-curvature reflector with a circular contour in the scan plane and a parabolic countour at right angles, has a feed offset from both axes of symmetry (see Figure 4-8).

Figure 4-8 Torus Multiple-focus Antenna. This antenna has a circular contour in the scan plane and a parabolic contour at right angles to the scan plane. (Courtesy of SatCom Technologies, Inc. an RSI Company.).

Figure 4-9 The Simulsat Multiple-focus Antenna. The Simulsat antenna is a rectangular section of a large sphere. (Courtesy of Antenna Technology Corporation).

How is the Quality of an Antenna Determined?

The quality of an antenna is determined by how well it concentrates the radiation it intercepts from a target satellite to a signal point and by how well it ignores noise and unwanted signals coming from sources other than the targeted satellite. Three interrelated concepts—the gain, the beamwidth, and the noise temperature—describe how well an antenna performs. These are very useful in judging whether or not to purchase any particular dish.

Antenna gain is a measure of how many thousands of times a satellite signal is concentrated by the time it reaches the focus. For example, a typical well-built, 10-foot diameter, prime-focus dish will have a gain of 40 decibels or 10,000, which means that the signal is concentrated 10,000 times at the focal point. This gain is primarily dependent on three factors. As the size of a dish increases, more radiation from space is intercepted. Thus, if the area of an antenna is doubled, the gain should be doubled. Gain also increases with increasing frequency, because higher-frequency microwaves being closer in frequency to light, behave a little more like light. Thus, they do not spread out as would waves in water, but can more easily be focused into straight lines like beams of light. (In fact, since the gain of a microwave antenna is proportional to the frequency squared, a signal with twice the frequency will be reflected by an antenna with four times the gain. To illustrate, if the gain is 10,000 when a signal of 5 gigahertz is received, then it will be 40,000 at 10 gigahertz). Gain is further determined by how accurately the surface of an antenna is machined to exactly a parabolic or other selected shape. Even small distortions in the surface of a dish can cause an antenna to loose substantial gain (see Table 4-1). Therefore, an antenna that has ripples in its surface will behave more poorly than one that is smooth and is closer to its designed shape. Antenna efficiency is a measure of how true the reflective surface actually is. Efficiencies vary from 55 to 65%; this means that typically 35 to 45% of the incoming signal is lost and does not reach the feedhorn.

The beamwidth of an antenna is a measure of how well it can "see" into a very narrow region of space. This is an important property because satellites separated by 4 degrees or less and located more than 22,300 miles away appear to be very close together when viewed from the earth. As a beamwidth diagram shows (see Figure 4-10.), the signal from a chosen satellite is concentrated in what is called the "main lobe," while extraneous signals form what is called the "side lobes" or interference. The beamwidth is then defined as the width, in degrees, of the main lobe. A poor-quality dish will not clearly pick up the signal and will see too much noise; i.e. it will have a lower main lobe and larger side lobes.

Loss of Gain versus Surface Distortion

Distortion (Inches)	Loss of Gain (Percentage)
0.01	2
0.05	17
0.10	44
0.25	288

Table 4-1

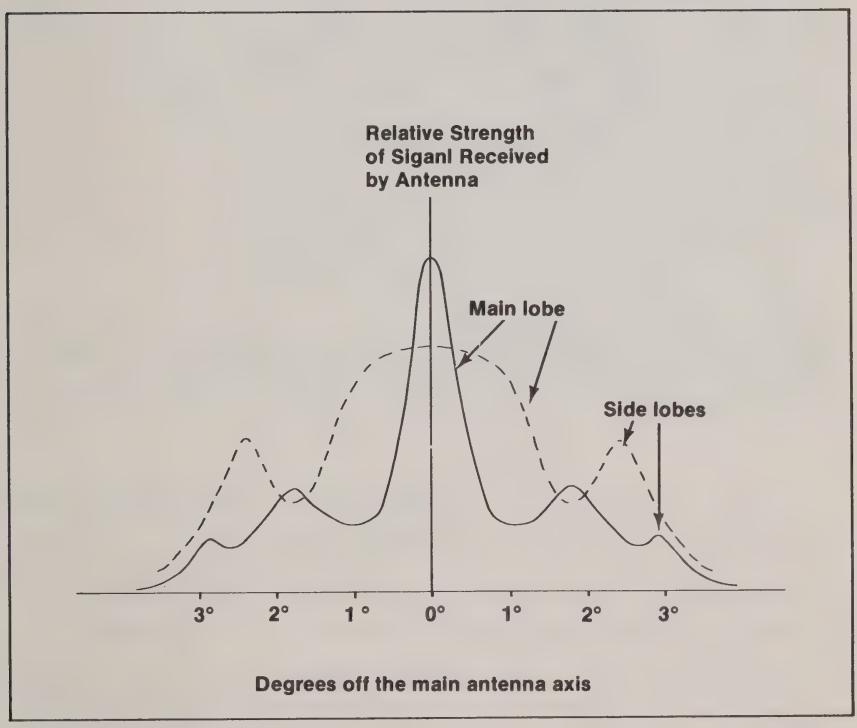


Figure 4-10 Comparison of Lobe Patterns. The better antenna has a narrower main lobe and smaller side lobes.

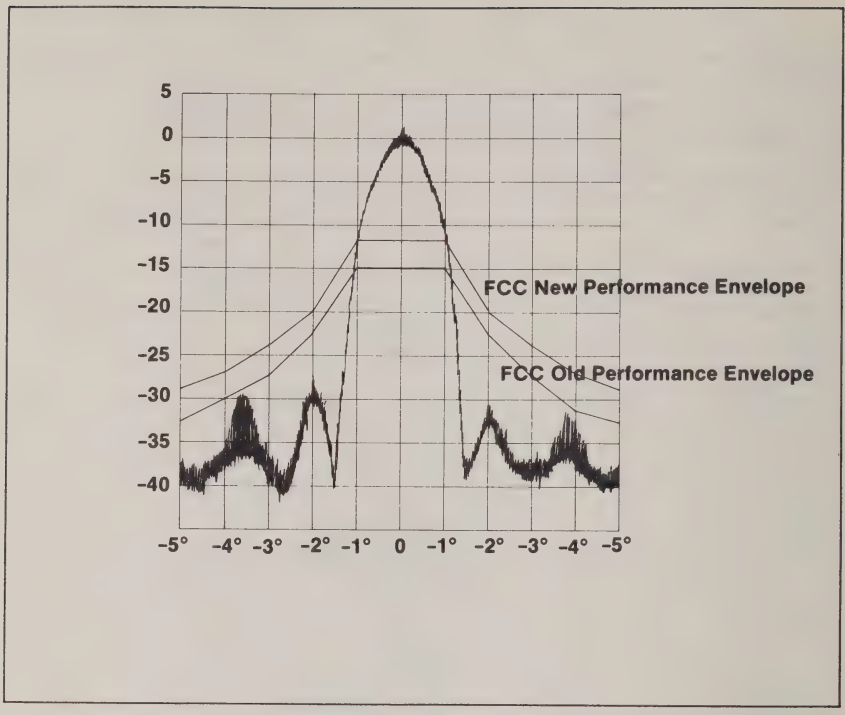


Figure 4-11 FCC Antenna Performance Envelope and Actual Performance Chart. The side lobes of an antenna should fall below the FCC requirements.

Each antenna design has an intrinsic beam pattern with a given amount of main and side lobes. The width of the main lobe, the beamwidth, decreases as both the frequency of the satellite message and the antenna diameter increase. When less reflector area is blocked, as in the case of antennas with offset feeds, side lobes can be lower.

Beamwidth patterns are somewhat different from the theoretical predictions. Side lobes will increase with irregularities in the smoothness of antenna reflective surface. They are also larger because radiation reflected off the feedhorn/low noise amplifier structure, the edges of the dish, and the surrounding terrain find their way into the feedhorn and garble the desired signal. The situation can be improved if a dish has a smaller ratio of focal length to diameter (the F/D) so that it sees less of the surrounding environment (see Figure 4-12). A similar result can be obtained if a reflective shroud is affixed around the rim of

an antenna, just like putting blinders on a horse so it will see only in one direction, straight ahead (see Figure 4-13).

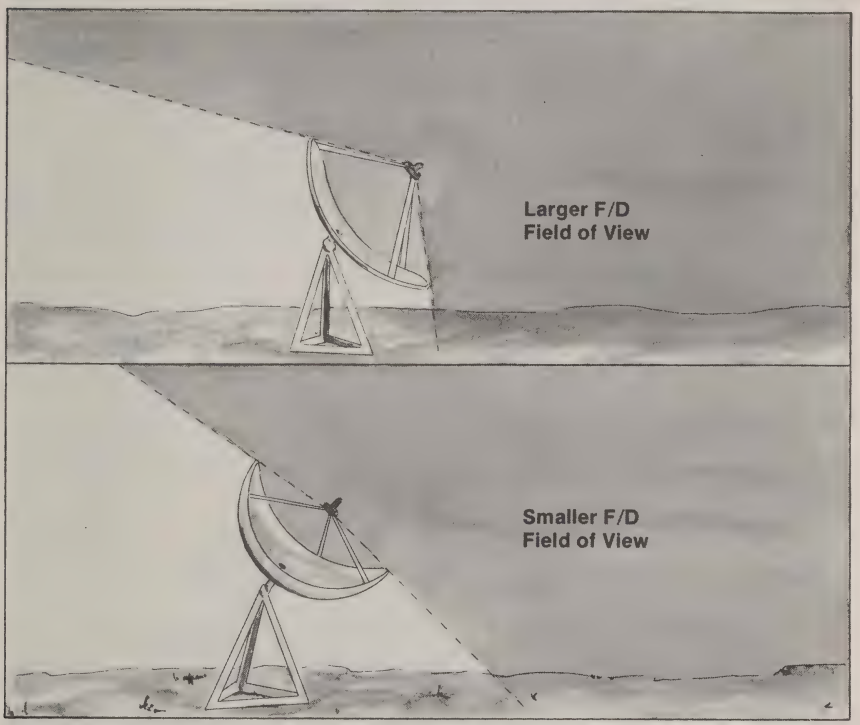


Figure 4-12 The Effect of Focal Length to Antenna Diameter Ratio. An antenna with a smaller F/D sees less of the "noisy" surrounding terrain.

Figure 4-13 Cassegrain Antenna with Protective Skirt. The rim aids in shielding the TVRO from unwanted interfering signals and noise. (Courtesy of Scientific Atlanta, Inc.).

The difference between an excellent and a poor-quality antenna is easily seen in their beamwidth patterns. It is important to understand that even apparently small changes in design can effect the "vision" of a dish. For example, even if square and round prime-focus antennas cut from identical larger dishes have the same surface areas and gain, they may have quite different lobe patterns.

Finally, the performance of antennas is measured by the noise that is detected along with the signal. Antennas unavoidably detect noise coming from many man-made or natural sources. In general, it is the natural noise sources that affect microwave transmission, since the frequency of man-made noise (e.g., electrical motors, fluorescent lights) is too low to effect microwave transmissions. If an antenna has a narrow beamwidth and acceptable small side lobes it will have a relatively low noise temperature.

What is Interference?

Interference occurs when unwanted signals are received along with the desired satellite message. In some cases, the garbling of the message can be so severe as to completely ruin a broadcast. Four types of interference can be identified.

Perhaps the most common and irritating form of interference is caused by reception of nearby microwave signals using the same or an adjacent frequency band. Reflections of microwaves off buildings or even from passing cars are responsible for such a local pattern of interference. When these interfering signals are sufficiently powerful they are detected by a TVRO antenna and can ruin a broadcast. Surprisingly, in some situations, moving an antenna just a few feet can significantly reduce interfering signal levels. Of course, in those situations where interference is very powerful, a TVRO might have to be moved miles or installed in a specially protected area.

The FCC allocation of microwave frequencies in the region of satellite transmissions identifies some possible sources of interference (see Table 4-2). Line-of-sight relays by local telephone companies that share common frequencies are the prime contributors of interference. This is so even though the carrier waves transmitted from satellites are specially altered to give them a different identity from Ma Bell signals.

Assignment of Microwave Frequencies and Possible Sources of Interference

Frequency Band (GHz)	Potential Source of Microwave Interference
0.960-1.350	Land-based air navigation systems
1.350-1.400	Armed forces
1.400-1.427	Radio astronomy
1.427-1.435	Land-mobiles: police, fire, forestry, railway
1.429-1.435	Armed forces
1.435-1.535	Telemetry
1.535-1.543	SAT - maritime mobile
1.605-1.800	Radio location
1.660-1.670	Radio astronomy
1.670-1.700	Meteorological - Radiosound
1.700-1.710	Space - research
1.710-1.850	Armed forces
1.990-2.110	TV pickup
2.110-2.180	Public common carrier
2.130-2.150	Fixed point-to-point (non-public)
2.150-2.180	Fixed - omnidirectional
2.180-2.200	Fixed, point-to-point (non-public)
2.200-2.290	Armed forces
2.290-2.300	Space - research
2.450-2.500	Radio location
2.500-2.535	Fixed, SAT
2.500-2.690	Fixed point-to-point (non-public)
	Instructional TV
2.655-2.690	Fixed, SAT
2.690-2.700	Radio astronomy
2.700-2.900	Armed forces
2.900-3.100	Maritime radio navigation
2.900-3.700	Maritime radio location
3.300-3.500	Amateur radio
3.700-4.200	Common carrier (telephone) Earth Stations*
4.200-4.400	Altimeters
4.400-4.990	Armed forces
4.990-5.000	Meteorological - radio astronomy
5.250-5.650	Radio location (coastal radar)
5.460-5.470	Radio navigation - general
5.470-5.650	Maritime radio navigation
5.600-5.650	Meteorological - ground based radar
5.650-5.925	Amateur
5.800	Industrial and scientific equipment
5.925-6.425	Common carrier and fixed SAT
6.425-6.525	Common carrier
6.525-6.575	Operational land and mobile
6.575-6.875	Non-public point-to-point carrier
6.625-6.875	Fixed SAT
6.875-7.125	TV pickup
7.125-8.400	Armed forces
8.800	Airborne Doppler Radar

Table 4-2

In some situations, stray signals from adjacent satellites or from uplinks targeting adjacent satellites can be detected by a TVRO earth station. These can cause troublesome interference with broadcast reception. Two types of this adjacent satellite circuit interference can occur, uplink and downlink interference (Figure 4-14). The downlink variety occurs when a relatively poor-quality TVRO dish with large side lobes detects unwanted signals from an adjacent satellite. Uplink interference occurs when stray power from an uplink dish pointed towards an adjacent satellite is detected by the target satellite and relayed to the TVRO antenna. In all cases, interference will come from transmissions occupying the same bandwidth as the one being viewed. Thus, if the transponder 10 messages are being viewed, only signals on transponder 10 from an adjacent satellite or uplinked to an adjacent satellite would be powerful enough to potentially cause problems.

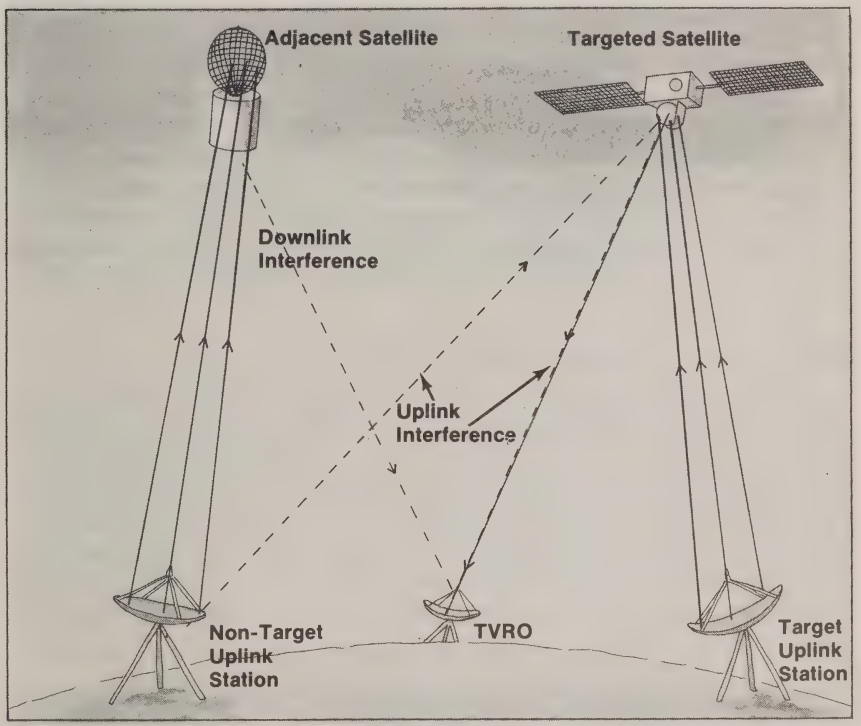


Figure 4-14 Adjacent Satellite Interference.

A third possible source of interference is from channels adjacent to the selected transponder. However, this would only occur with the use of a low-quality earth station that discriminates poorly between signals of opposite polarization and that does not filter out adjacent-

frequency microwave messages. For instance, in a well-designed TVRO station, channel 12 should not receive "crosstalk" from channel 11 or 13.

Finally, a predictable form of interference is caused by the sun. Twice a year the sun lines up directly behind each satellite for periods of approximately ten minutes per day for two or three days. Since the sun is a source of massive amounts of radio noise, no transmissions can be received from satellites during these sun-outage times. This unavoidable type of interference should be expected during the normal course of operation of an earth station.

The FCC has made two rules aimed at reducing problems with interference. Since the deregulation of TVRO earth stations, owners and manufacturers of antennas are not mandated to follow these regulations. However, they are based on careful study and are useful guidelines. First, a set of well-defined standards restricts the amount of allowable side lobes that an antenna can exhibit (Figure 4-11). Second, a procedure known as a "frequency coordination" has been established to protect broadcasters and other communicators operating commercial systems. This three-part procedure begins with an on-site engineering analysis to measure levels of microwave interference. Next, a coordination notice is issued to inform other microwave users of the intent to install the facility. Third, the FCC issues an operating license so future microwave users can easily check to see where other users are located.

How Large Must an Antenna Be?

Perhaps the most regularly asked question is why such a large antenna must be used. Today, small 3-foot dishes that are capable of receiving higher-frequency television broadcasts directly from satellites are often compared to larger, more common antennas. To answer this question, we can analyze the four factors influencing the antenna size requirements: satellite footprint, thermal noise, antenna diameter and gain, and interference. These determine a minimum ratio of signal-to-noise required so that earth station circuits can deliver a clear television picture.

The amount of power received on earth depends on the footprint of a telecommunication satellite. Signal power could be increased up to a point limited by the capacity of the launch vehicles and by the capability of the on-board solar cells. This is already being done. The same effect can be accomplished by the use of a more directional, higher-gain antenna. However, such a downlink antenna would have a footprint covering only a portion of the country. This is acceptable only for certain types of broadcasts. The bottom line is that if the power receiv-

ed on earth can be doubled, then an antenna with half the surface area could be used. The newer satellites do have more available power. However, since the average lifetime of satellites is about eight years, it will be many years before required antenna size will decrease substantially.

The higher the level of noise "seen" by a dish, the larger the gain has to be to deliver an adequate electronic signal. In general, antenna gain is increased by the increasing of its diameter. In higher latitudes, an antenna must be aimed at a lower angle to point towards the arc of satellites. (This angle is called the look angle.) It thus sees more of the warm, "noisy" ground as well as a thicker layer of warm atmosphere. All of the improvements in performance that increase gain and lower antenna noise allow use of smaller antennas, and vice versa. Similarly, a location that has unnecessary sources of interference will need either a larger or a higher-quality antenna to maintain an adequate signal-to-noise ratio.

All these factors taken together determine the minimum size of an antenna that can perform adequately. For conventional 6/4 gigahertz broadcasts, a minimum antenna diameter of from 6 to 15 feet is required in the continental United States. Higher-frequency broadcasts are most often relayed to more restricted areas and therefore have higher EIRPs or higher power levels. Thus, much smaller antennas are capable of detecting the so-called direct broadcasts that have frequencies in the range of 12 gigahertz.

Of course, it is not safe engineering practice to use the smallest possible antenna for a given application with no margin for error. To illustrate, a severe rainfall could result in as much as a 50% loss of signals and a complete loss of television signal. Also, both satellite transponders and TVRO earth station equipment degrade over their lifetime so that EIRP slowly decreases and earth station gain is reduced. Even small movements in the orbital position of satellites or a slight misalignment in the feed of a dish can reduce gain and lower picture quality.

Antenna Construction and Installation

The materials, construction, and installation must be carefully considered if antennas are to function properly over a long lifetime. Microwave dishes made of fiberglass, aluminum, steel, and even of wood or metal screen may perform well when new. However, the performance of dishes made of less durable materials may degrade in time. For example, wood may warp, and a thin screen mesh can be easily damaged by rocks and hail. A thin-wall dish with poor structural support will also be more likely to warp. Allowances must be made for the expan-

sion and contraction of alumimum and steel antennas for them to retain an accurate shape. Quality dishes may be made from one or many pieces if the designs of each are correct.

An effective antenna surface is not necessarily guaranteed by the use of a quality material and design, but also depends upon an excellent manufacturing process. All antennas must be capable of reflecting microwaves. Dishes of wire mesh, aluminum, and steel are metallic and thus already reflective to microwaves, but fiberglass dishes must have metal-based coatings incorporated into their design. The challenge of manufacturing a fiberglass antenna is to embed wire screen, aluminized mats, or other metallic materials in the fiberglass resin while retaining an accurate surface. These are some of the factors that may or may not make antennas durable.

The overall performance of an antenna can vary according to the location of installation. The shadowing of a satellite signal by local obstructions such as trees or buildings can degrade performance as much as poor alignment can. On the other hand, an antenna mounted on the ground with foliage and buildings blocking out all but the desired satellite signal may lower interception of environmental noise and improve the overall performance. The same strategy is sometimes used when antennas are installed in pits with only a view of the target area. Unlike a regular TV antenna that must be mounted very high to avoid obstructions and receive a clear signal, a satellite receiving antenna needs only a clear "view" of the satellite. Dishes are generally mounted at ground level where winds are usually lower than on roofs. A closed attic would be a convenient location of installation because no land would be used and winds would be no problem. Unfortunately, this is not possible because most of the signals would be absorbed by the roof materials. Even using a glass cover to protect from rain or wet snow is not a reasonable alternative, since glass substantially reduces the power of 4-gigahertz microwaves.

Are Earth Station Antennas Safe?

Earth receiving stations are perfectly safe. The levels of microwave radiation present even after amplification by the antenna and the low noise amplifier at its focus are negligible. Antennas do not get hot, do not fry birds, and do not transmit dangerous radiation. The voltage delivered to power the amplifier at the focus is at the highest only 24 volts, about twice that of a car battery. There is no danger, except perhaps from a poorly mounted antenna falling over in an extremely strong wind.

Antenna Mounts

Earth station antennas must be securely mounted and capable of aiming accurately towards any chosen telecommunication satellite. Using a mount that provides stability and pointing accuracy is a critical part of designing an earth station, because well-designed dishes with narrow beamwidths target very small portions of the sky. For example, a 5-meter antenna with a beamwidth of 1° sees only twenty-six ten thousandths (1 in 26,000) of the visible sky, so the signal from a targeted satellite would be lost if this dish moved even a relatively small distance off target. Without an adequate mount, such movement is possible when winds blow across the large sail-like, surface areas of the antenna.

Mounts must be strong, rigid structures, firmly attached to both the dish and the installation location. They can be bolted onto concrete pads and other structures or can have their bases actually embedded in concrete. An antenna should be secured as close to the ground as possible, preferably in a protected area. Dishes mounted on rooftops must be affixed to a structurally sound building able to resist strong uplifting winds. Of course, the smaller the antenna, the easier it is to mount it on a roof or any other chosen location.

Types of Mounts

There are two broad classes of structures used for mounting earth station antennas. One consists of assemblies having two axes at right angles to each other, such as the azimuth-over-elevation (az-el) or the x-y mounts. The other class of structures, including the polar and modified polar mounts, has just one main axis of movement used in aiming towards the geosynchronous arc of satellites.

The x-y and az-el mounts are similar except for the placement of their two axes (Figure 4-15 and 4-16). The x-y has one axis parallel to the ground like the parallel bars of a gymnast. The az-el has its lower axis perpendicular to the ground so it has movement like a spinning figure skater. In the United States, this elevation angle ranges from 7° in northern Maine to 25° in southern Florida.

Installation of both mounts is rather easy because the only adjustment necessary before securing the assembly is to align the body of the mount in a level plane, with the midpoint of the lower axis pointing to the center of the satellite arc. Although these mounts are simpler to manufacture than are one-axis assemblies and can be installed by a competent "do-it-yourselfer," they are more cumbersome to use in targeting a satellite because two axes of movement must be carefully adjusted.

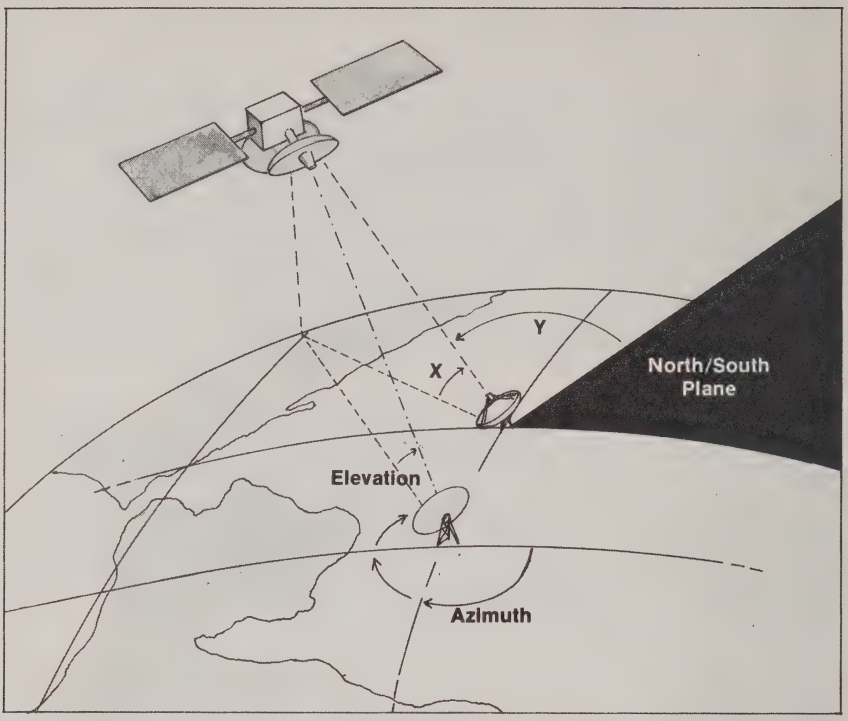


Figure 4-15 Geometry for Azimuth-elevation and X-Y mounts.

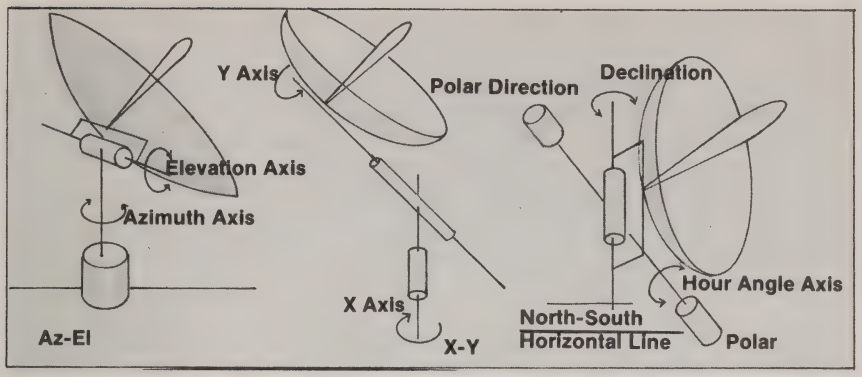


Figure 4-16 Antenna Mount Geometries. This diagram shows how the axis or axes are rotated for these three classes of mounts.

Polar mounts have the advantage of being able to locate satellites from the eastern to the western sky by movement along only one axis, the polar axis (see Figure 4-17). The development of these single-axis mounts was motivated by efforts to reduce the costs and increase the flexibility of earth stations. Both mounts must be aligned within one degree of true north, and the declination angle must be properly set for that latitude. When these mounts are installed, their bodies must be carefully pointed towards true north, and the declination angle must be adjusted so that the antenna aims at the equatorial ring of geosynchronous satellites. Then the antenna is rotated through its polar axis until the signal from any one satellite is detected. Next, the antenna is adjusted to target this vehicle accurately by maximizing the power level of its signal. If the installation happens to be correct immediately, rotating the dish along its polar axis will allow every satellite to be accurately targeted. However, this is not usually the case, because the body of the mount must be slightly readjusted. While this readjustment is being performed to arrive at the perfect settings, the whole assembly can easily move because the base of a polar mount is not yet securely

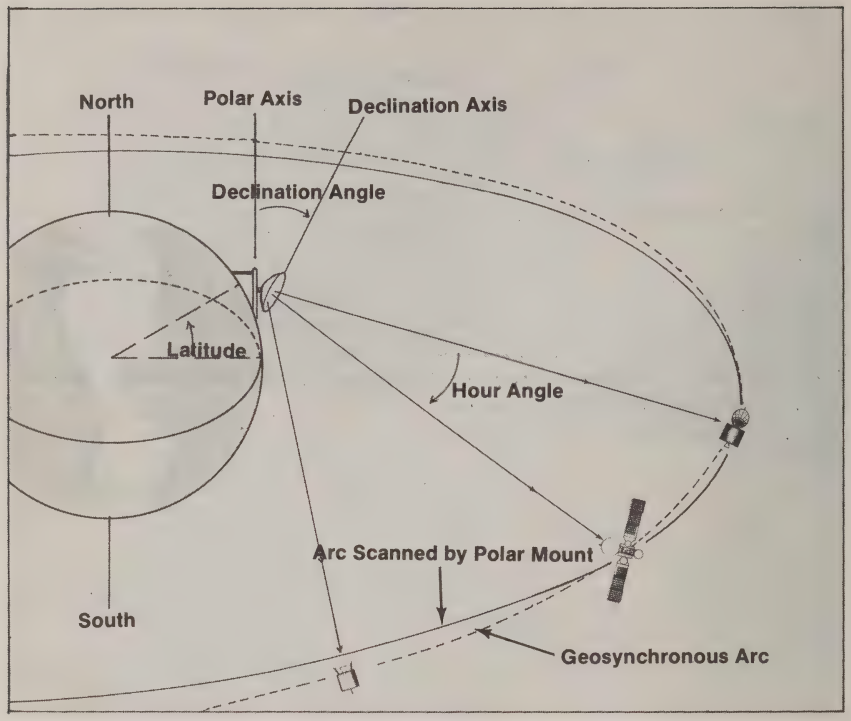


Figure 4-17 Geometry for Polar Mount. Note that any polar mount not located at the equator scans the arc of satellites (dotted line) with some error (solid line).

fastened. Only when the nearly perfect alignment position is found is the mount securely affixed. For this reason, many antennas having diameters in excess of 5 meters (more than 16 feet) often have az-el mounts to avoid the difficult installation of a polar mount.

Polar mounts scan the arc of satellites perfectly when they are located on the equator. However, the scanning arc of a polar mount at higher latitudes is not exactly coincident with the geosynchronous satellite orbit (see Figure 4-17). The modified polar mount corrects for most of this error by having its polar axis tilted a small amount away from the earth's axis while still remaining in a north-south plane. The antenna beam then sweeps more closely to the geosynchronous arc of satellites.

How to Aim an Antenna

Once a mount is properly installed, satellites can be tracked if the necessary adjustments are made either by hand or automatically by an electric or an electrically-driven hydraulic motor. Hydraulic sys-

tems can work well if designed properly, but require more upkeep and maintenance than electrically-driven crankscrew assemblies. In the early days of satellite communication, when there were only a handful of these geosynchronous vehicles, most large-dish antennas were installed facing just one satellite in a permanently fixed position. Today, many dishes for specific uses are still fixed towards one target. To illustrate, a cable TV company often has three dishes aimed permanently to target key television broadcast satellites. Multiple-focus dishes are also carefully pointed towards the geosynchronous arc and then fixed in that position.

The Feedhorn and its Support Structure

Signals concentrated by an antenna are captured by a device called a "feedhorn," which channels them into a low noise amplifier. Just as the quality of an antenna determines how radiation is "seen" and what its beamwidth pattern is, so does the feedhorn "illuminate" a dish. An excellent-quality feedhorn will illuminate the entire dish equally; that is, it will see incoming radiation along the antenna axis reflected from the entire antenna surface but from nowhere else. A poorer-quality feedhorn will see some unwanted radiation coming from the surrounding environment and will miss some desired signal being reflected off an antenna. Feedhorn and antenna designs must complement each other to capture as much signal and as little noise as possible. Using a poor-quality feedhorn can degrade the performance of an otherwise excellent dish. A low-quality or an improperly located feedhorn can dramatically increase side lobe interference. Consumers should make sure that a supplier understands the interaction between these components and does not simply piece together an earth station.

How Does a Feedhorn Work?

Feedhorns, also known as waveguides, are metal, hollow pipes of circular, rectangular, or other cross-sectional shapes that transmit radio waves (see Figure 4-18). They can be compared to fiber-optic cables that transmit light along their lengths. Signals cannot be transmitted through such waveguides unless they have a wavelength shorter than one half of the dimensions of the waveguide. This very useful property allows an earth station to discriminate signals of vertical and horizontal polarization. For example, if signals having a wavelength of 1 centimeter reach a waveguide having a cross-section of 2 by 0.3 centimeters, only those waves polarized in the wider dimension, 2 centimeters, will pass through.

All feedhorns have designs based on this property. They channel radiation reaching the focus of an antenna into a waveguide that accepts only one of the two polarizations. In one design that uses a

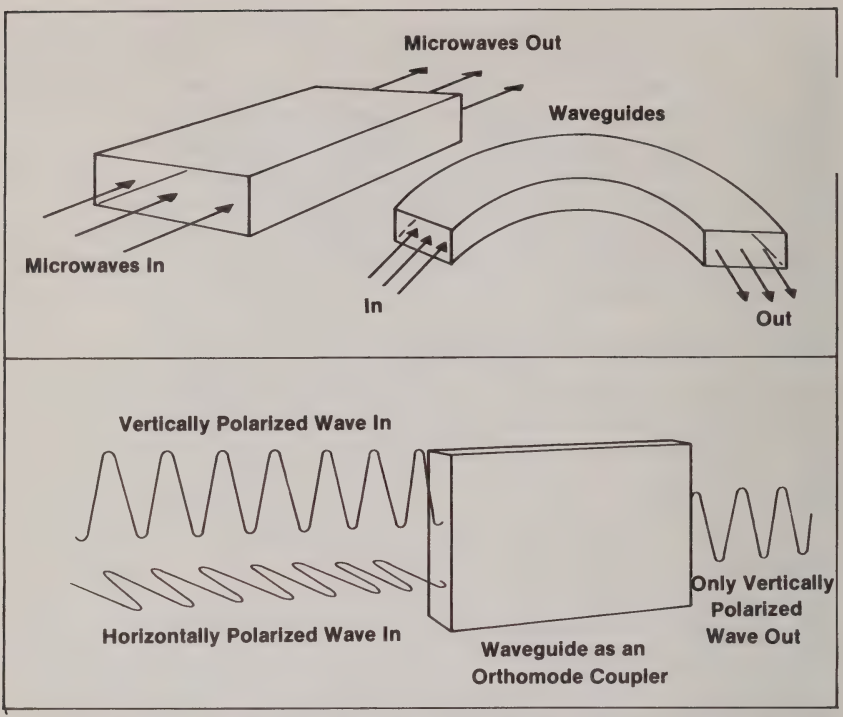


Figure 4-18 Waveguides. Signals with horizontal and vertical polarizations can be separated by waveguides.

single rectangular waveguide the whole feedhorn/low noise amplifier assembly is rotated to accept either horizontally or vertically polarized signals (Figure 4-19). Some feedhorns incorporate a waveguide design called an "orthomode coupler," which uses two rectangular boxes at right angles to separate horizontally and vertically polarized signals for relay to two separate low noise amplifiers. Such a dual low noise amplifier assembly can receive all channels from any one satellite at once without the rotating of equipment at the antenna focus (Figure 4-20). When only a single polarization can be detected by the feedhorn, a control on the in-door receiver activates a small electric motor that rotates the assembly between horizontally and vertically polarized signals. Recently, feedhorns which can electrically select between polarizations have been developed. Such single-polarization feedhorns therefore need not be manually rotated to switch between polarizations but can be activated simply by changing channels on the video receiver.

The choice between a dual- or single-polarization feedhorn is based on convenience and the cost difference between a more expensive feedhorn and an extra low noise amplifier. The feedhorn must be

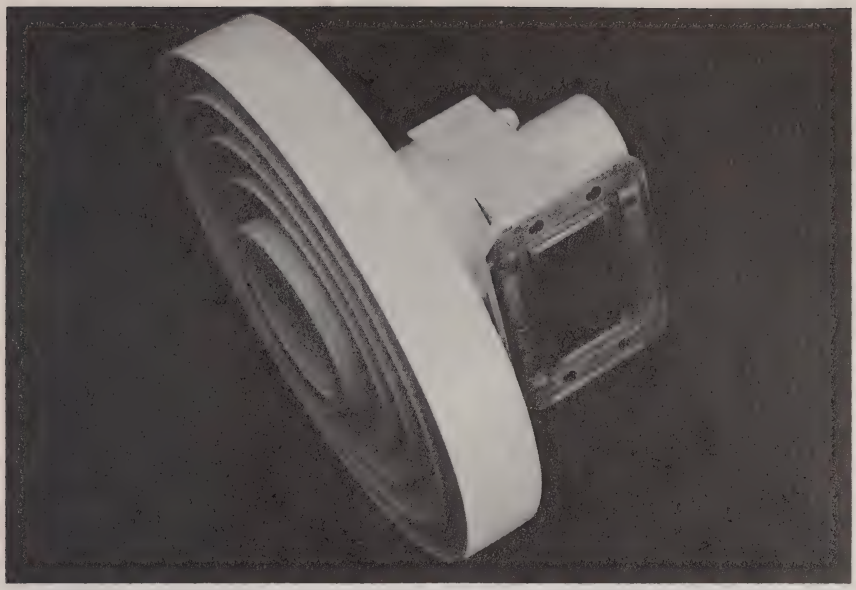


Figure 4-19 Single Polarization Feed. This feed must be rotated 90° to detect the horizontally and vertically polarized signals. (Courtesy of Seavey Engineering Associates, Inc.).

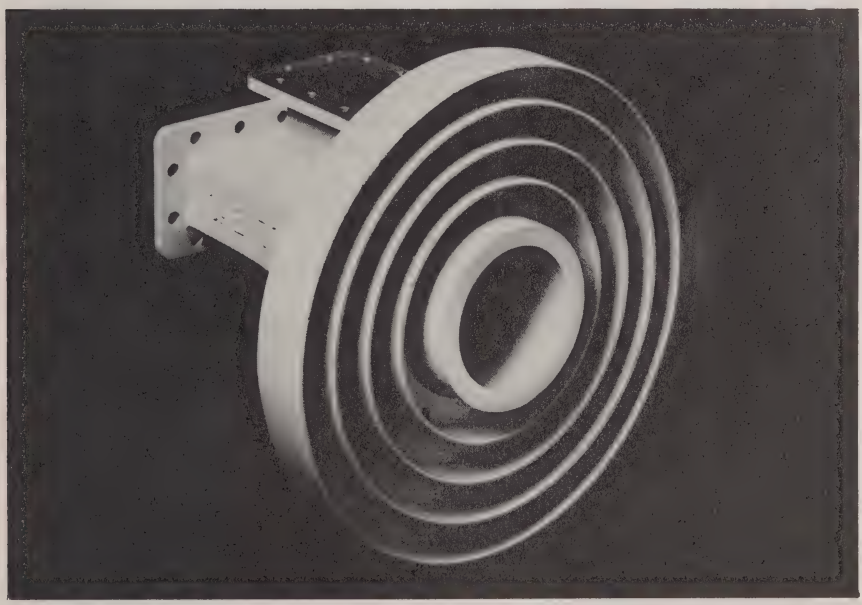


Figure 4-20 Dual-Polarization Feed. Both vertically and horizontally polarized signals can be simultaneously detected with this feed which has two output ports. (Courtesy of Seavey Engineering Associates, Inc.).

carefully aligned with the direction of polarization so that all the power is received and so that the feedhorn design allows a clear discrimination of one polarization at a time. This cross-polarization discrimination permits clear reception of only one channel at a time.

What are the Types of Feedhorns?

Of the many designs of feedhorns, the two most common are the "scalar" and the "cow-bell." A scalar feedhorn has a series of concentric rings that direct signals from an antenna into a central waveguide. A cow-bell device is shaped like an inverted bell and directs radiation into a smaller waveguide at the base of this structure. These and other types of feedhorns are shown in Figure 4-20. The feedhorn used with a Cassegrain antenna is specially designed and directs signals from the subreflector at the focus to a low noise amplifier behind this dish. A buttonhook-type feedhorn also channels radiation down a long curved waveguide attached to the center of an antenna to a rear location.

The feedhorn/low noise amplifier assembly must be held securely in place exactly at the focus of the antenna so that signals will always be received at their maximum power. A "buttonhook" support, which can also be a waveguide on its inside, is affixed to the center of the antenna. Such supports need to be securely fastened to the rim of a dish by wires so that no movement will occur. A "moon-lander" (also known as a "milk stool") assembly consists of three or four adjustable poles that are attached either to the rim or the surface of a dish and of a dish and meet in its center at the feedhorn. Both types of supports must be carefully designed to be compatible with the overall antenna/feedhorn structure and function. All supports shadow the incoming radiation and reduce the amount of available signal. The buttonhook support and the moon-lander attached on the dish surface have the additional problem of shadowing some of the signal reflected off the dish towards the feedhorn. The smaller the dish antenna the more crucial is this shadowing difference. Because the signal received from a satellite is so very low in power, all the components concentrating and directing it into the low noise amplifier must be designed to work as a well-matched team.

The Low Noise Amplifier

The low noise amplifier (LNA) receives a concentrated signal from the antenna and has the crucial function of increasing its strength by 100,000 times while keeping the noise level very low so that a sufficiently powerful message will reach the video receiver. The antenna and low noise amplifier working in unison are the most important parts in determining how well an earth station works. The

LNA is the first "active" or electronic component in the processing of a satellite signal.

Improvements in LNA design have been made possible by recent advances in transistor technology. The original LNAs were very bulky and often had to be immersed in baths of extremely cold liquid nitrogen or liquid helium to keep noise levels acceptably low. The development of the gallium arsenide field effect transistor, a special low noise transistor, has made the modern LNA possible. When properly installed, the LNA has a very long lifetime and is hardly ever in need of maintenance. The best low noise amplifiers now can operate at noise temperatures of 60°K, even though they actually are at a much warmer room temperature. Such amplifiers produce noise as if they were composed of conventional transistors maintained at 60°K (which equals an extremely cold -351°F at which even air would freeze) without the use of expensive and bulky baths of liquid helium—a great scientific feat indeed. Amplifiers typically used in earth stations with rated noise temperatures of 100 or 120°K are much less less expensive than 60°K LNAs because they produce slightly more noise at these higher temperatures.

Since low noise amplifier production costs have steadily declined, moderately priced earth stations have proliferated. Once the new transistors were developed, improvements in manufacturing skill led to the marketing of quality devices at declining prices. Today use of the microstrip construction technique permits whole electric circuits to be etched directly on very thin pieces of materials such as plastic, quartz, or sapphire. The drop in both price and rated noise temperature was rapid. In the early 1970's top-quality LNAs with a noise temperature of 250°K sold for $4000; in 1976, a 150°K unit sold for $4000. At the end of 1977, 100°K LNAs were selling for less than $4000, and 150°K units for below $2000. By 1982 the consumer could purchase an LNA rated at 100°K for below $500!

How Does an LNA Work?

Low noise amplifiers are designed to magnify signals over the whole bandwidth they see by equal amounts so that no distortion in the received message is introduced. The LNA is analogous to a stereo pre-amplifier in that it provides the first critical electronic amplification. The LNA is bolted directly onto the feedhorn so that a minimal amount of incoming signal will be reflected back to the antenna. Inside the small metal box that houses the LNA, microwave signals are usually amplified in two or three stages to achieve the overall 100,000 times increase in strength necessary. A cable attached to the back of this device transmits the message to the next stage, the receiver. This cable or a second wire connected to the rear of the LNA

delivers approximately 15 to 24 volts DC to provide power for this amplification (Figure 4-21). When the LNA has only one connecting cable, power is transmitted from the receiver by connecting a thumb-sized device called a bias-tee (also known as a DC block) into the line. Amazingly, the output signal leaving the LNA is still very weak at a power level of approximately one hundredth of a millionth of a watt!

Figure 4-21 Low Noise Amplifier. This unit bolts directly onto a feedhorn. The thinner lead provides power while the thicker routes the satellite signal to an in-doors receiver. (Courtesy of Dexel, Inc.).

Until the 1980's most low noise amplifiers simply amplified video messages the signal received from the satellite and relayed this 3.7 to be to 4.2 gigahertz band of frequencies (bandwidth of 500 megahertz) to a receiver. Some newer LNAs "downconvert" as well as amplify the signal. Downconversion, which means lowering the frequency of the signal, is a necessary step at some stage in earth station electronics to allow the original audio and extracted easily. A special type of low noise amplifier called a "low noise converter" (LNC) downconverts each channel in the 3.7 to 4.2 gigahertz signal part or all of the way to the demodulation range of frequencies. For example, one model lowers the frequency of each channel in turn to the 270 to 770 megahertz band, which still has the same 500 megahertz bandwidth as before. Another type, called a low noise block converter (LNB), simultaneously lowers the microwave carrier frequency of all satellite channels to the range in which signal demodulation is performed (see Figure 4-22 and 4-23).

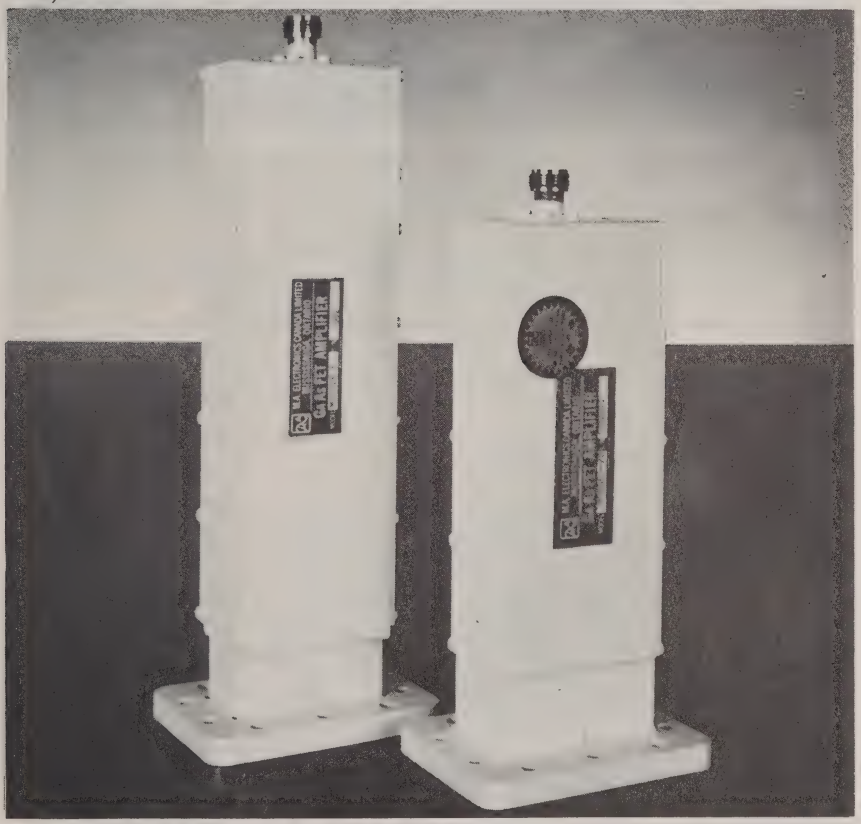


Figure 4-22 LNA and LNB. The LNB on the left downconverts the signal in addition to amplifying it. A standard LNA is on the right. (Courtesy of M/A COM, Inc.).

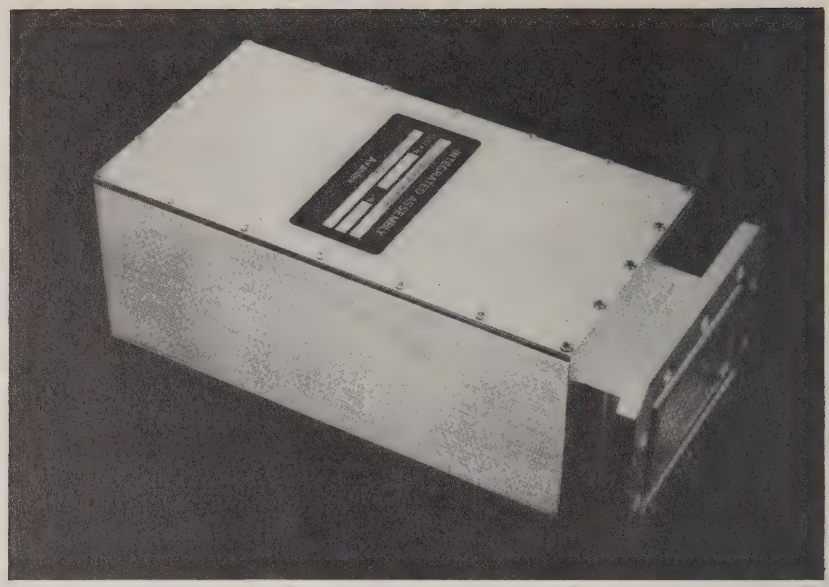


Figure 4-23 Low Noise Amplifier/Downconverter. This unit amplifies and down-converts the satellite signal. Input and output cables are not shown here. (Courtesy of Avantek Corporation.).

Low noise amplifiers have one weakness in their overall durability. Their special transistors act like fuses and burn up if the voltage powering their performance exceeds operational limits. Half of all LNA failures result from excessive voltages when unpreventable lightning strikes occur before the normal lifetime expires because of wear and tear.

How Does Heat Effect LNAs?

How well a low noise amplifier performs is determined to some degree by the temperature of the environment in which it operates. If the temperature rises from 77°F to 95°F, the gain will decrease by almost 3% and the noise temperature will increase by over 5%. Using a Cassegrain antenna in a hot desert climate is advantageous, since the LNA is mounted behind the dish out of the direct glare of the sun and therefore remains cool. If a 120°K LNA was exposed to direct sunlight and heated to 180°F, it would behave like a 150°K unit by adding much more noise to the signal. A protective cover can be used to house the electronics of the LNA to help keep temperatures low. These containers are often hermetically sealed by a rubber or enamel paint to shield the sensitive circuits from adverse climatic conditions. In addition, there is a clever method for improving the performance of an LNA. The first sensitive stages of the amplifier can be "spot-cooled" by a thermo-

electric unit operating at a low power of 2 to 5 watts inside the LNA metal box. For example, if a 120°K LNA was cooled to 0°F, the effective noise temperature would drop to 97.4°K, and the output signal-to-noise measure would improve by a full 26%.

How is the LNA Selected?

The choice of an LNA is determined by the selection of other components of the earth station and by cost. The sizes and types of antenna, feedhorn, and support-structure determine how much signal and noise an LNA receives. If the signal-to-noise ratio is too low, the highest quality low noise amplifier cannot rectify the problem, and picture quality will be poor. However, in most cases, a 120°K LNA contributes enough amplification with low enough noise so that the message sent via cable to the receiver is of adequate quality.

In general, the lower the rated LNA noise temperature, the higher will be its cost. Most earth stations now use devices rated from 80°K to 120°K. However, other factors enter into the retail price. An LNA that has a higher gain or has surge protection to isolate its sensitive components from power surges will usually cost more. The method of rating LNAs can also effect price. Some brands rated at 120°K are guaranteed to have noise temperatures below this figure, often by as much as 15 or 20°K; other less expensive brands rated at 120°K are usually very close to or even slightly higher than this value in their noise temperatures.

From the LNA to the Receiver

The antenna assembly is connected to the receiver and the modulator, which are housed in-doors, by a special type of wire, coaxial cable. Single wires of copper or aluminum are adequate for conducting electricity at the lower frequencies encountered in most familiar electrical devices. However, when higher-frequency radio waves are relayed on wires as electrical signals, these single strands of metal behave like antennas by radiating away most of the power. With exceptionally high frequency signals, such as those found in satellite communications, specially designed coaxial cables must be used to prevent almost complete loss or attenuation of the signal enroute to the video receiver. Such conductors are made of a piece of wire surrounded by an insulator, which itself is encircled in wire sheath that is connected to ground (see Figure 4-24 and 4-25). This grounded layer of metal inhibits the ability of the central conductor to act as an antenna. Therefore high-frequency messages are lost at a much lower rate as they travel down the coaxial cable and also external signals are not inadvertently detected.

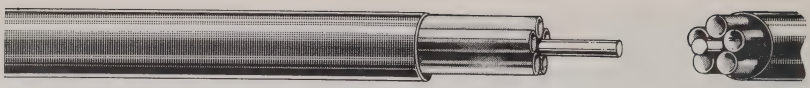


Figure 4-24 Coaxial Cable. The tubes surrounding the central conductor are filled with non-conducting air. (Courtesy of M/A COM, Comm/Scope Marketing, Inc.).

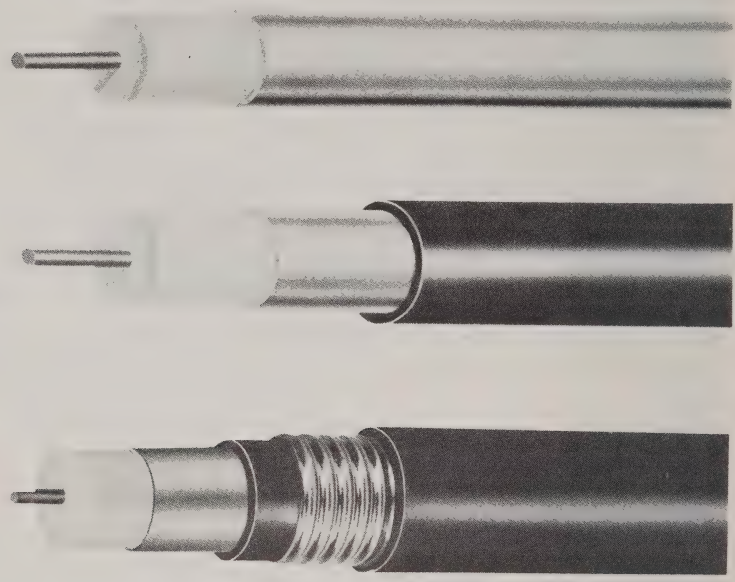


Figure 4-25 Coaxial Cable. These three examples of coaxial cable for high frequency signal conduction are protected to increasing degrees (top to bottom). The middle has a polyethylene jacket. The lower has two jackets as well as a corrugated chrome plated steel armor to prevent the cable from being excessively bent. (Courtesy of M/A COM, Comm/Scope Marketing, Inc.).

Coaxial cable that carries higher-frequency signals is designed to more exacting specifications and is almost always more expensive than "coax" for low-frequency transmissions. This is so because higher quality sheathing to prevent wires carrying high-frequency signals radiating away large amounts of power is more expensive. Errors made when installing TVRO equipment could cause more deterioration in performance if higher-frequency signals are used. To illustrate, if a coaxial cable is not properly connected to the rear of the low noise amplifier there will be over 70% more losses at 12 gigahertz than at 4 gigahertz. The reason for partially downconverting from the gigahertz to the megahertz range of frequencies at the LNA is to save money spent on coax and to minimize problems caused by installation errors. For example, coaxial cable such as RG-214 is rated for signals having frequencies of up to 10 gigahertz and must be used with conventional LNAs. However, if the microwave signal is partially downconverted in a low noise amplifier, then cable such as RG-59, which is less than one tenth the price of RG-214 coax, can be used to effectively transmit the lower frequency signal with adequately low attenuation (see Table 4-3).

Table 4-3

Properties of Coaxial Cable

Cable Designation	Decibels of Signal Loss (per 100 feet)			Outer Diameter (Inches)	Impedance (Ohms)	Maximum Useable Frequency
	1 gH	3 gH	5 gH			
RG/U 6	11	22	30	.332	52	
RG/U 8	9	19	28	.405	52	
RG/U 11	9	19	28	.405	75	100 MHz
RG/U 59B	11.5	25.5	41	.242	75	1 GHz
RG/U 213				.405	50	1 GHz
RG/U 214				.425	50	10 GHz
RG/U 217				.545	50	1 GHz

Coaxial cable is usually referred to as either hardline, coax, or foam or air dielectric coax depending on the construction of the sheathing material, the dielectric. Coax has one or two pliable metal grounded layers wrapped around a plastic dielectric. Foam or air dielectric coax uses either foam or compressed air as the dielectric material and is generally lower loss and more expensive than ordinary coax. Hardline is similar in construction to either of the previous two except it has a more rigid, ever lower loss metal sheath. Hardline is usually used in the main trunk lines of cable or other communication systems.

The length of coaxial cable must be considered when installing an earth station because power losses increase with length of cable. Most equipment manufacturers recommend RG-214 cable for runs of less than 100 feet. For longer runs low-loss, air dielectric cable is required. If the distance between the LNA and the receiver is substantial, the signal may have to be downconverted at the LNA, or booster amplifiers may be needed to recapture some of the lost power. Since cable television companies send their broadcasts over long distances, they use an extensive network of power boosters and splitters even though these signals are relayed over coaxial cable in the lower-frequency megahertz ranges. (Splitters take a signal from one main wire and send identical messages into two or more secondary wires). This minimizing of cable runs is also important because noise, which increases with cable length and decreases with cable diameter, is added to a satellite signal as it journeys from the output of the LNA to the input of a receiver.

In addition to being chosen accordingly to frequency specifications, coax must be impedance matched to both the low noise amplifier and video receiver. Each brand of coax has a characteristic impedance, a resistance to signal flow, measured in ohms (see Table 4-3). If the output impedance of the LNA does not equal the cable impedance, the signal will "see" this discontinuity and be partially reflected backwards. The performance of an earth station can be completely ruined if the wrong coax is chosen.

Thus, coaxial cable should be carefully selected so impedances are properly matched and so the frequency carrying ability is adequate. The distances between the LNA and receiver should be made as short as possible. Also, any connectors used must be rated to carry the frequencies chosen and all connections must be secure and waterproof.

The Video Receiver

The video receiver further amplifies the signal, downconverts the range of frequencies (if this has not already been partially done by the low noise amplifier), and then demodulates or extracts the original

broadcast audio and video signals from the carrier waves. When additional stereo information is added to the satellite broadcast signal, an additional piece of equipment, a stereo demolulator, is necessary to extract this stereo sound. The receivers used in the early days of satellite communications were large, clumsy devices whose weight was almost a measure of cost. The modern video receiver, which is usually light, small, and attractively packaged, can be compared to the more familiar stereo receiver. A well-designed video receiver is reliable, easily maintained, and has high-quality audio and video reproduction. (Figure 4-26, 4-27, 4-28, and 4-29).

Figure 4-26 Video Receiver. This Drake is capable of digital tuning, variable audio tuning and remote control. (Courtesy of R.L. Drake Company.).

Figure 4-27 Video Receivers. (Courtesy of M/A COM, Inc.).

Figure 4-28 Video Receiver. (Courtesy of Harris Corporation.).

Figure 4-29 Video Receiver. This receiver has a meter on the front panel which allows the strength of satellite signals to be measured. (Courtesy of Comtech Data Corporation.).

How are Channels Selected?

As well as amplifying the weak signal received from a low noise amplifier, downconverting, and demodulating the carrier waves, the video receiver selects from among the channels relayed. Most satellites can relay as many as 24 channels. A device called a tuner, like the channel selector on a radio or a television, allows any one channel to be viewed by the pressing of a button or the turning of a knob on the face of the video receiver. Some commercial receivers do not have this capability but are "semi-agile," whereby channels are selected by the actual changing of plug-in circuit boards. Other commercial receivers (Figure 4-30) are fixed to one preselected satellite channel.

Figure 4-30 Multichannel Video Receiver. This unit is really 6 video receivers at once. It is used in commercial installations. (Courtesy of Avantek Corporation.)

Those completely "agile" tuners in consumer brands of video receivers are the component most susceptible to breakdowns. Higher-quality tuners "hold" each channel more clearly and are less

apt to receive interference from adjacent channels. Synthesized tuners, which are found in all fixed and semi-agile receivers but only in some agile receivers, have this desirable quality. These use a separate crystal (as in a crystal watch) or another component specifically designed to select the frequency of each channel. They are much less subject to "drifting" than are tuners that use a continuously variable device to tune from channel to channel.

The number of channels that can be viewed at the same time is limited by the number of receivers on-hand. However, the output from an earth station with just one receiver can be received by any number of television sets. The simplest earth stations use just one receiver, while more sophisticated sytems, like those employed by cable TV and SMATV systems, are designed to allow many channels to be viewed simultaneously. In those cases in which the satellite signal is partially downconverted at the antenna focus by an LNB or LNC, a special compatible receiver that does not duplicate this function is needed. Figure 4-31 illustrates three possible arrangements that can be used in earth station designs.

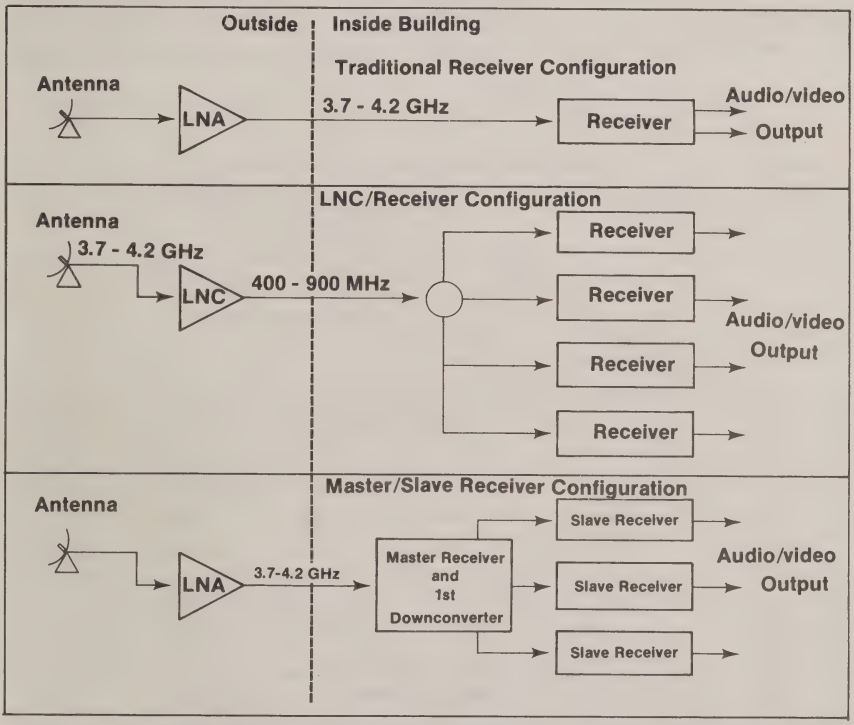


Figure 4-31 Possible Designs for TVRO Earth Stations. The bottom two designs are capable of simultaneously receiving more than one television channel.

What is Threshold Extension?

The threshold of a video receiver is a measure of how weak an input signal can be before the television picture quality is unacceptable. Threshold is measured by a ratio of signal-to-noise power. When the video-receiver input is adequate—i.e., above threshold—the receiver output is linearly related to the input. A linear relationship means that for a given change in input, there is a given change in output. To illustrate, if an input of 1 watt results in an output of 5 watts, then an input of 2 watts would result in an output of 20 watts. The linear relationship between input and output is important because a TV broadcast of a scene having one area twice as bright as another would not look proper if the reproduced picture had that area only 50% brighter. This could occur if the video receiver was not functioning linearly when the input level was below threshold. Many receivers have built-in meters that show how much power is being received from a satellite and help determine whether a signal is below threshold.

Most video receivers have thresholds in the 6- to 9-decibel range (see Figure 4-32); that is, the input signal must be from 4 to 8 timnes more powerful than the noise. As the input level falls below threshold, impulse noise is visible as "sparklies" in the television picture and as

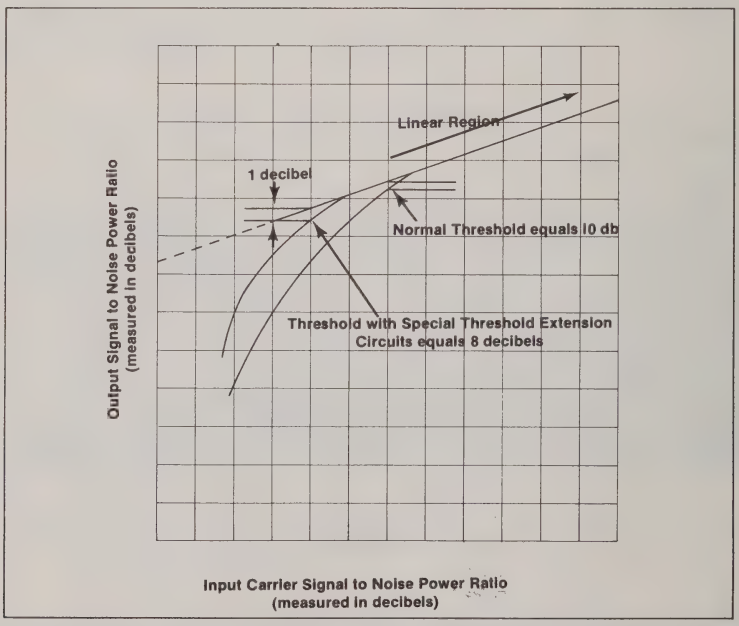

Linear Region
1 decibel
Normal Threshold equals 10 db
Threshold with Special Threshold Extension Circuits equals 8 decibels
Output Signal to Noise Power Ratio (measured in decibels)
Input Carrier Signal to Noise Power Ratio (measured in decibels)

Figure 4-32 Graph of Video Receiver Output versus Input Power. This graph shows how receiver threshold is determined.

random noise in the audio message. This occurs in normal television reception when a signal from a distant station is too weak. Even the best video receiver will be incapable of functioning properly if the signal-to-noise ratio generated by the antenna/low noise amplifier/ cable lead is too low.

Threshold extension techniques are used with some video receivers in an attempt to lower the threshold in order to improve reception of signals that would otherwise be just below threshold. Of the three techniques for lowering threshold, using the best possible electrical components that contribute the lowest amounts of noise to a signal being processed by a receiver is by far the most effective.

To provide a fuller understanding of the second and third threshold extension techniques, the reason for using frequency modulation in relaying satellite signals must be more clearly explained.

The satellite downlink signal when detected by a TVRO has a very low power and a moderate amount of noise. The frequency modulation technique spreads the 4.2-megahertz television bandwidth across the available 36-megahertz transponder bandwidth. This use of a wider bandwidth allows for detection of an acceptable-quality TV signal even if the carrier signal-to-noise level ratio is quite low.

The second method used to lower video receiver threshold allows only a portion of the bandwidth of the signal from a satellite transponder to be detected in order to reduce noise. This is possible because the amount of noise increases or decreases in direct proportion to the size of the bandwidth. This procedure works well until a television signal using the full 36-megahertz bandwidth appears. Then parts of the signal are lost and picture quality deteriorates.

The third and most sophisticated threshold extension method uses a circuit that not only switches on and reduces bandwidth when the signal is too weak for clear reception, but also "tracks" and centers its reduced bandwidth around the frequency where the television signal is strongest. This technique can lower threshold by as much as 3 decibels, which means it can satisfactorily detect and demodulate a signal with half the power that it could without the circuit. Unfortunately, these threshold extension circuits may cause, as well as solve, problems. If a transponder circuit is occupied with subcarrier audio signals in addition to a television broadcast, such a circuit may deteriorate rather than improve a weak video signal because not enough video signal power may be contained in the reduced bandwidth. In the worst case, an interfering signal from a source such as a local telephone company may be strong enough so that the threshold extension device would track the wrong signal and completely ruin a broadcast.

Video Receiver Quality

A quality video receiver must have a low threshold while maintaining a sufficiently wide bandwidth to clearly decipher all the information relayed by each satellite transponder. An inexpensive lower-quality brand might boast a low threshold but this threshold could have been achieved by using a narrow bandwidth. This may be adequate for most video reception conditions. However, if audio subcarriers are also present in the higher frequency portions of the 36 megahertz available band, these may not be received at all.

Receiver Signal Power Levels

The original signal sent from the TV camera, the "baseband" signal, has a strength of approximately three thousandths of a watt. This signal has been modulated onto carrier waves, amplified, and attenuated many times, and finally demodulated on its journey to each television set. There are many changes in power of a typical satellite communication link before the message is reassembled by the video receiver.

Modulators and Converters

Modulators and converters are similar pieces of equipment that process the television baseband signal from a video receiver into a form that can be detected by a television (Figure 4-33, 4-34, and 4-35). This

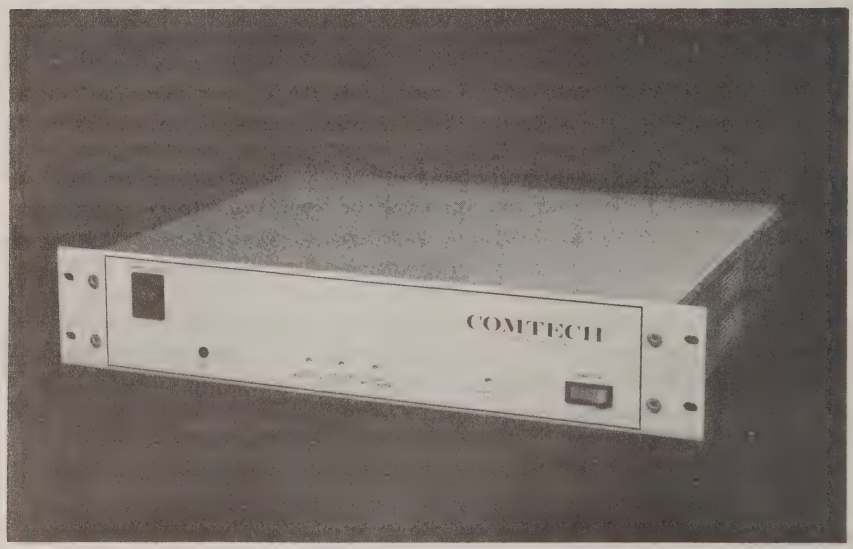


Figure 4-33 TVRO Modulator. This device is designed for use in commercial systems. It is capable of modulating the output signal from a video receiver onto a range of television channels. (Courtesy of Comtech Data Corporation).

baseband signal, which contains all the video and audio information as well as the necessary synchronization pulses to recreate a television picture, can be fed directly into a television monitor. A conventional television, however, has built-in demodulation circuits, so the baseband signal must be modulated before being relayed to a TV set. A home video-tape recorder (a VCR), like a TV monitor, processes the raw baseband signal. Signals from a video receiver could be fed directly into a VCR whose built-in modulator allows the output signal, to be properly inter-preted by a television set.

Figure 4-34 TVRO Modulator. This modulator is specifically designed for use with TVRO earth station satellite receivers where video and audio signals are detected on separate carriers on a given transponder. (Courtesy of Blonder-Tongue Laboratories, Inc.).

Baseband signals can be modulated so that they can be received by any chosen VHF or UHF channel on a television. A typical home earth receiving station uses a modulator that feeds signals into either channel 3 or 4. These channels have frequency ranges of 60 to 66 megahertz and 66 to 72 megahertz, respectively. Once the electronics are hooked up and channel 3 or 4 is selected, the satellite broadcast channels are selected by the tuning of the video receiver. The FCC allocation of 58 channel frequencies is illustrated in Figure 4-36 for comparison purposes.

On the other hand, a satellite master antenna system may use a different arrangement (Figure 4-37). Each receiver is set to a given transponder and has its own modulator tuned to a chosen UHF and VHF television channel. Channels are then selected by the rotating of a knob on the television set.

A cable company uses another procedure. Broadcasts from each transponder are first modulated into a different frequency band and then relayed via cable lines to each customer's home. A set-top converter (Figure 4-38) selects from the many channels and usually modulates the signals into just one TV channel. Modern cable television systems can be constructed using lines that can carry up to 58 channels side by side (two lines could then carry 116 channels).

Figure 4-35 Stereo Demodulator. This device allows a TVRO to receive stereo music in addition to video signals. It is essential in receiving broadcasts such as Music TV. (Courtesy of R.L. Drake Company).

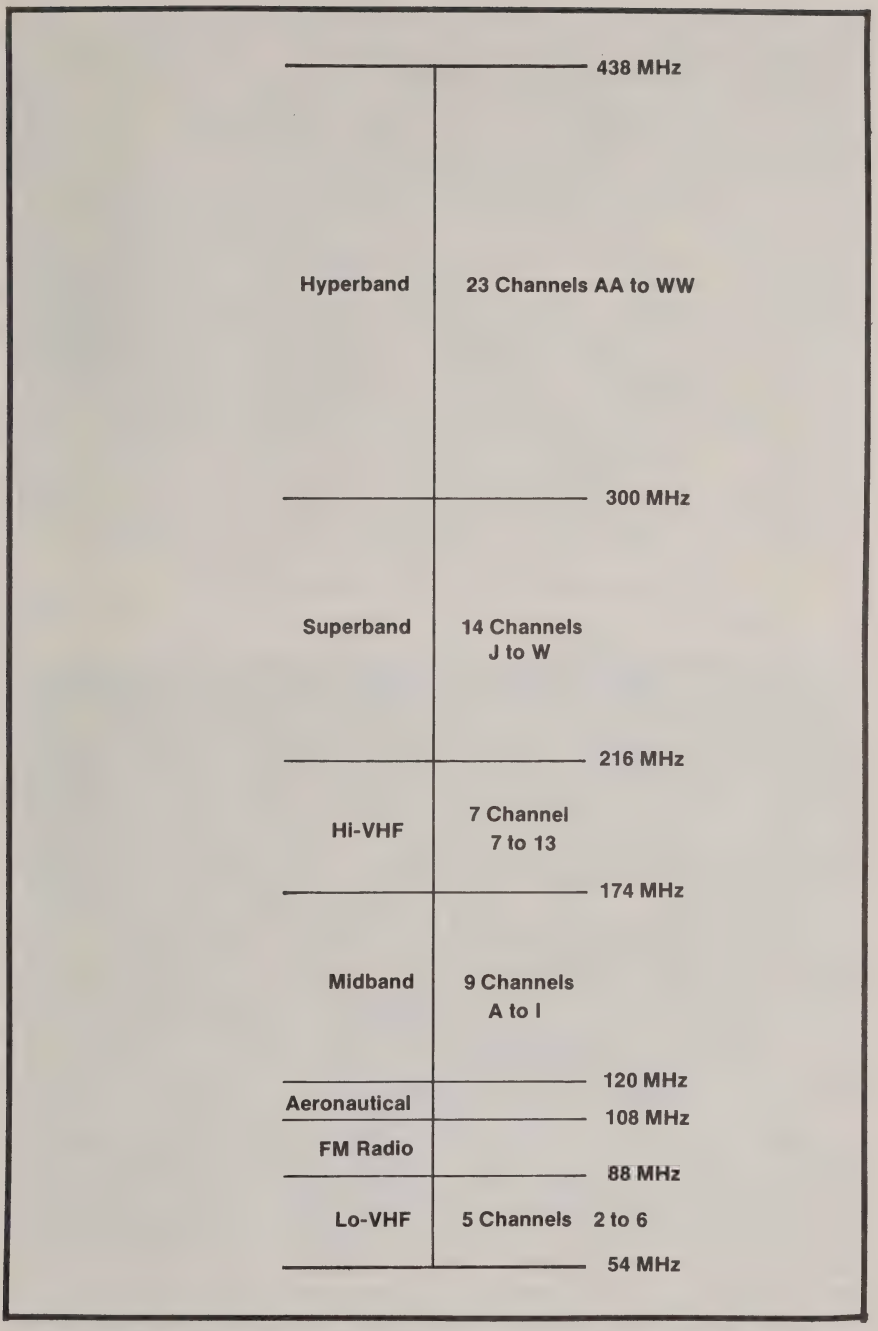


Figure 4-36 Cable TV Frequency Bands. Each channel has a 6-megahertz bandwidth.

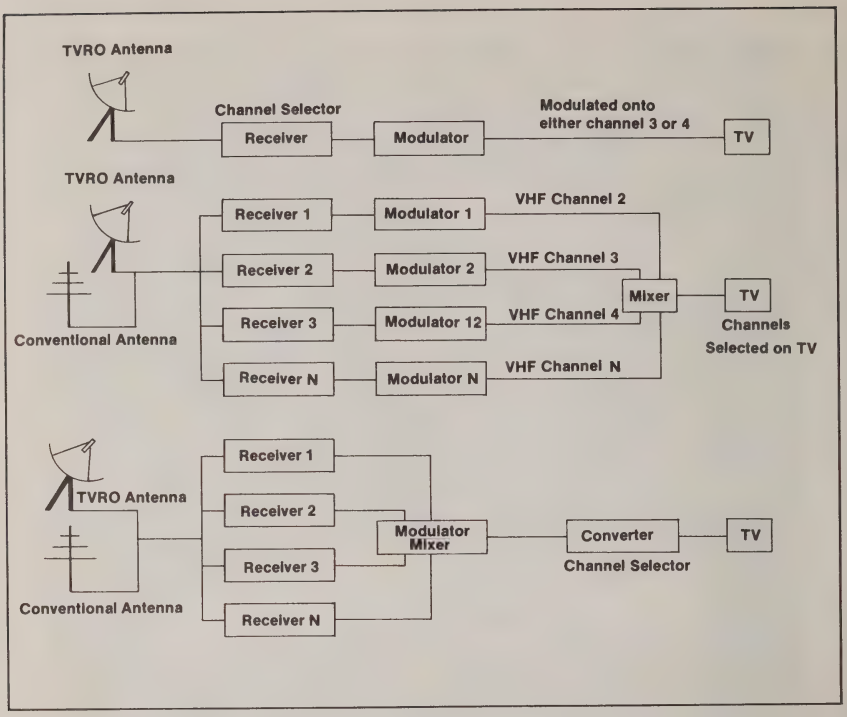


Figure 4-37 Arrangements for Modulating Signals onto TV Sets.

The baseband signal is amplitude modulated onto cable lines fed into a television set. Amplitude modulation is chosen because relatively high signal power levels can be used and because the transmission bandwidth must be maintained relatively narrow so that as many channels as possible can be carried by each cable line. This system is different from that used in FM broadcasts where wide bandwidth transmissions of relatively low power are favored.

What are Addressable Converters?

Addressable converters, recently introduced, are either one-way or two-way devices. One-way addressable converters can receive and respond to digital signals from a cable TV company (Figure 4-39). These small computers can turn subscriber service on and off, keep track of billing, offer once-only special programming only to consumers who wish to receive it, and respond to consumers' needs for changes in program menu with speed and flexibility. For example, if a subscriber wished to drop three channels and add two different ones, a repairman would not be required to visit his home because all changes could be

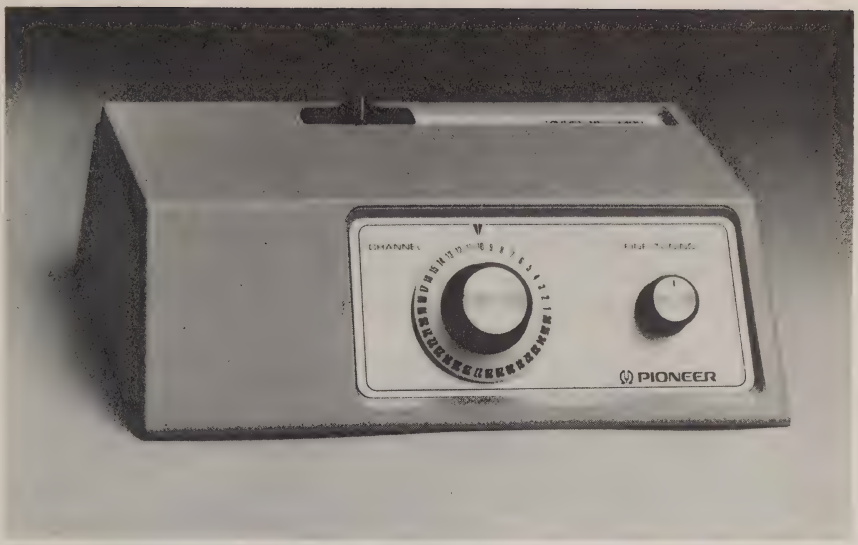


Figure 4-38 36-Channel Tunable Converter. (Courtesy of Pioneer Communications of America, Inc.).

Figure 4-39 One-way Addressable Terminal and Remote Control. (Courtesy of Pioneer Communications of America, Inc.).

managed from a central location by means of an addressable converter. This form of control is becoming an economic necessity as the complexity of the business increases and many more customers and transactions are being managed.

A two-way addressable converter allows the customer to "talk back" to the cable control center via a home keyboard (Figure 4-40). Such services can include home entertainment, burglar and fire-alarm protection, medical emergency alert, electronic newspapers, banking, mail, shop-at-home, instant opinion poll voting, videotext, environmental monitoring and control, and energy management.

Figure 4-40 Two-way Interactive Home Terminal. (Courtesy of Pioneer Communications of America, Inc.).

Scramblers and Decoders

Scramblers are devices that code a broadcast so that the information is not recognizable unless decoded. Such encryption techniques can be used to prevent pirating of cable TV, satellite relays, and many other transmissions of private information. Scramblers can be built into set-top converters so that one-way addressable cable systems can periodically change a code to maintain secrecy. In a similar fashion, satellite transmissions can be coded so that only those who own a decoder and have access to the proper combination will be able to view a broadcast. In late 1983, the Home Box Office Network became the first to demonstrate a scrambling system for satellite broadcast TV. This system would be very secure because HBO could send any one of 72 quadrillion combinations it desires over the satellite link and could change the combination at any point in time.

Although, scrambling can be a viable method of deterring all but the most sophisticated pirates, it may not be economically justified in all markets because it may cost more to buy scrambling and decoding devices than the sum of all revenues recovered. The fact remains that improvements in satellite receiving technology have certainly created an unprecendented opportunity for signals to be intercepted at any location under a satellite footprint. Therefore, broadcasters and other communicators are attempting to curtail loss of their revenues by whatever reasonable technical or legal means are available (Figure 4-41).

Build Your Own Earth Station?

Some especially talented individuals can build a well-functioning earth station. In fact, in the mid 1970's when the first home earth station was built by a Stanford professor, the cost was comparatively so low that many commercial manufacturers were quite surprised.

If a "do-it-yourselfer" has the time, piecing together a prime-focus or other antenna may be a reasonable undertaking. Antennas can be built from wood, metal screening, aluminum pieces, or other materials if a smooth, true shape can be well approximated. The mounting assembly for the feedhorn and the low noise amplifier must be rigid and must cast as small a shadow as possible onto the dish. It must also be designed so that the feedhorn can be adjusted to the precise center of the dish focal point or points.

Figure 4-41 Encoder and Decoder. The Orion decoder is fully addressable under computer control by the transmitting station. Each decodeer may be authorized to receive up to 49 different categories of programming material. (Courtesy of Oak Satellite Corporation).

Some talented electrical engineers may even attempt to build the remainder of an earth station. However, the competition between established electronic firms is such that high-quality feedhorns, low noise amplifiers, receivers, and modulators can be purchased today at prices competitive with those a "do-it-yourselfer" could achieve. Therefore, before an individual decides to build his own system, the comparative cost and the exacting design criteria necessary for a high-quality TVRO station must be carefully considered.

If the decision is made to purchase a system, one of two routes can be followed to obtain a high-quality system. TVROs can be purchased as a complete or "turnkey" system from one dealer, or each component can be purchased independently from different dealers or from the manufacturers, if possible. In either case, a consumer should understand the theory of TVRO systems well enough to judge the quality of each part.

Purchasing and Operating an Earth Station

Before an earth station is purchased, a consumer should have a practical knowledge of the many pitfalls enroute to receiving a clear

television picture from a satellite. This is just as important as understanding the theory of satellite communication, because some dealers selling such systems have a limited and often confused view of the field. Although many dealers are competent, the business is rapidly growing and has yet to see many vendors of inferior, poorly matched, or poorly installed systems fail.

A "site-check," testing the TVRO earth station to be purchased at the planned location of operation, is a crucial first step. The system should deliver a clear, stable television picture. If reception quality is only marginal during a site-check, then the picture during a rainstorm or other not-so-perfect conditions will be very poor. It has been estimated that as many as 10% of all sites in larger cities are subject to a sizeable amount of interference from sources such as the local telephone company. A dealer should be able to suggest alternatives if microwave interference is encountered. For example, if an interfering signal is detected coming from the east, the dish can be moved so it is screened by a tree, it can be placed behind a metal fence, it can be fitted with a reflective shroud around its rim, or it can be moved to a location such as the opposite side of the house.

All components to be purchased must be tested during a site-check. Just because a friend in another city used a 10-foot dish with a similar electronic package does not mean that the system will work elsewhere. A 10-foot antenna may function well in an area near the center of a satellite footprint, but could be inadequate in other locations where a signal might be more than 50% or 1.8 decibels weaker. An antenna should be of sufficient size to have adequate gain and should have a narrow beamwidth to allow detection of a minimal amount of noise and unwanted signals. The gain of antennas depends on their quality. For example, a 10-foot dish can have gains that vary from as low as 38 decibels to as high as 40.1 decibels, a difference of 2.1 decibels or 62%! Similarly, low noise amplifiers can have gains that vary from as low as 38 to 40 decibels (6310 to 10,000 times amplification) to as high as 60 decibels (1,000,000 times amplification). If the distance between the LNA and the indoor receiver is long, then a more expensive, lower noise, higher-gain LNA will be required to compensate for cable losses. If improper cable or connectors are used, too much signal will be lost and too much noise will be picked up on the way to a receiver.

Many types of receivers are available for purchase today. New designs receiver are being constantly improved upon because "bugs" or engineering problems often require small design changes to be fully eliminated. It is prudent policy to check the track record of any device being considered for use. Receivers should be of sufficient quality to produce a clear television picture. Lower-threshold units can function better in marginal signal reception situations than can receivers with

higher threshold, which are usually less expensive. Agile receivers (those that can switch between channels) with synthesized tuning are apt to be more durable than those with continuously variable tuning. Receivers that have built-in signal power meters, VU meters, on the front panel allow a dish and feedhorn to be carefully aligned to receive a maximal satellite signal. Units also have other differences. For example, some are designed for use with LNAs that downconvert at the dish, while others have built-in modulators. Some receivers are equipped with outputs to specifically pick up the wealth of audio information relayed via satellite as subscribers on television signals. These two main audio subcarriers are located at the 6.2- and 6.8-megahertz positions in the 40-megahertz video band. In view of all these variations in receiver design it is clear that the needs of each situation must be carefully assessed before a given brand is chosen.

Consumers should be aware of the differences between commercial and home-market equipment. Commercial antennas and electronics have been available for longer than 20 years and have, therefore, been carefully tested and improved. Commercial earth stations are generally more expensive but more durable, more carefully designed, and have higher-quality outputs than those sold to the home market. Television station owners cannot afford to lose a signal during marginal reception conditions, and therefore purchase commercial-grade equipment. Unlike the home market where dealers are often in the satellite communication business as a sideline, most commercial dealers are often manufacturers or manufacturers' representatives. It is wise to carefully check on the status of a dealer to determine whether he will be able to service locally installed equipment. Guarantees may only be honored if a dealer is still in business when problems arise.

Once a system is purchased, the equipment must be correctly installed and operated. Some antenna mounts must be aligned with true north. True north is determined by pointing towards the geographic location of the North Pole and not towards the location of the magnetic pole, as would a compass. The difference between these directions, the magnetic declination angle (also known as the deviation angle), is caused by variations in the amount of magnetic materials found in the earth. A compass needle may point more than 25 off true north in some places. In order to correct for magnetic declination determine the value for each locale by asking a local dealer or surveyor, or by consulting the U.S. Geological Survey Magnetic Declination Map or an aeronautical deviation map.

When the mount, antenna, and electronic equipment are installed, the necessary pointing angles can be calculated from equations or from plots of these equations. To illustrate, use a satellite finding map (see Figure 4-42) to find the elevation and azimuth angles so an az-el

device can be aimed toward each satellite. The procedure for doing so goes as follows. Determine the longitude and latitude of the earth station site from an ordinary map or atlas. Then calculate the difference between the site longitude and the chosen satellite longitude. This difference and the site latitude is then used with the satellite pointing map. For example, if Satcom IV at 83°W is being located from Houston, Texas with longitude 95.5°/W and latitude 29.5°N, then the difference of 12.5° is used with 29.5°N to find that the elevation angle and azimuth angle necessary to aim at this satellite are 53° and 24°, respectively (see Figure 4-42).

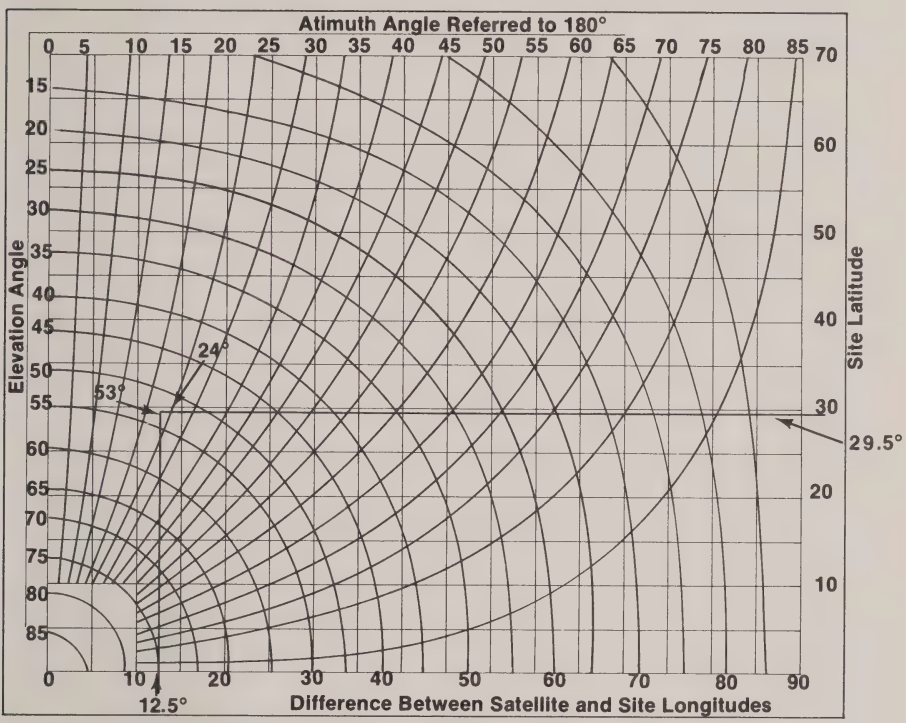


Figure 4-42 Satellite Finding Chart. This chart determines the elevation and azimuth angles required to aim towards any chosen satellite.

Once a system is installed and is providing its owner with unmatched home entertainment, it must be adequately maintained to continue doing so. The amount and type of maintenance necessary is determined in part by the climate and in part by the type of equipment purchased. A desert climate will cause more wear due to excess heat, while a maritime climate may result in problems with rust and corrosion. For example, LNAs may last years longer if their containers

are packed with dessicants, materials that absorb any excess water that may have leaked in. Probably the most common failure of earth stations occurs when connections in cable lines are penetrated by water and shorted out. All cable fittings should therefore be covered with heat shrinking or tar wrap materials. Some commercial installations use cables that contain pressurized air between the central conductor and the surrounding metal sheath in part to avoid moisture problems. Other maintenance procedures are dictated by common sense. For example, after a severe wind storm, antenna alignment should be checked. Even deviations of 1/16 of an inch can cause poor reception. Also, if remote controlled hydraulic mount pointing systems are used, the fluid should be changed once a year even in sealed systems.

5. PROGRAMMING

Television as an entertainment medium is changing. As recently as the early 1970's, the three familiar national networks and, to a certain extent, the Public Broadcasting System, produced or controlled most television programming. The majority of UHF and cable TV companies used network shows almost exclusively, although some did their own productions for local distribution.

The evolving forms of the satellite entertainment industry can be compared to a newsstand, which carries hundreds of newspapers and magazines but has nothing to do with their writing, production, printing, or distribution. In the broadcast business the "writing and production" is the work of independent program producers. The "publication and distribution" is the work of companies and engineers who build, launch, service, and operate the satellites and ground stations. The "sales" are the work of cable TV and other distribution companies. Only now because of the new technology can there be innovative programming and means of distribution that allow the customer to enjoy the luxury of satellite television. As a result, the whole structure of television as an entertainment medium is evolving to radically new forms.

Other Television Broadcasters

Since the advent of television, social, economic, and technological advances have changed the production and viewing of television programming. For example, at one time locally produced and broadcast TV could not be exported to distant areas. Programming originating in New York could not be viewed in Chicago. This became possible because of the installation of cable lines and line-of-sight microwave stations. Now satellites link cities even closer together. These innovations have allowed development of a variety of ways for programming to be received and distributed.

Some special television broadcast modes or TV stations that have evolved over the years select from the large pool of programming relayed by satellite. These distribution methods are subscription television (STV), low power television (LPTV), multipoint distribution systems (MDS), cable television, and satellite master antenna television (SMATV).

STV is similar to conventional television broadcasts except that a monthly or per-program fee is charged to customers. The operators of subscription television protect their transmissions from unauthorized use by scrambling their broadcasts. The subscriber's set is furnished with a decoder to receive an unscrambled signal and a clear picture. The service has been successful. Since the first experimental testing of STV was permitted by the FCC in the early 1950's, at least 500,000 sets have been outfitted for subscription television.

Similarly, low power television, a conventional, over-the-air transmission service, relays scrambled broadcasts. LPTV is intended to serve the hidden, unserviced, and underserviced rural areas of the country with a combination of local origin and national programming. Although cable TV provides excellent service for many small towns, the dwelling density in many rural areas is so low that cable costs would be prohibitive. Segments of the population living in these areas, as well as groups in large cities not serviced by other modes of broadcasting, are the market for LPTV. LPTV has been entitled the "gold rush of the 1980's" because, following granting of the first station permit on May 14, 1982, at least 6500 applications for operating such businesses were received by the FCC within the span of a few months.

The first low power television station, the 17 kilowatt Minnesota ministation, is typical of the breed. It has a 33-mile broadcast radius, which is much smaller than that of a standard 100-kilowatt VHF television station. However, the smaller station can be on the air for $80,000, which is substantially less than the average outlay of $2 million required for a conventional television station. Because the average cost for installation of trunk lines for a cable TV distribution system is $12,000 per mile (in 1982 dollars), LPTV is also much more economical than cable in outlying areas.

MDS are microwave broadcasting facilities that typically receive programs from a satellite and then rebroadcast them to many individual rooftop antennas in close vicinity. With the permission of the FCC, MDS has recently been allowed to expand from 2 video channels to 31 channels. MDS is economically strong because it reaches the investment break-even point at only 4,000 to 8,000 subscribers compared to approximately 50,000 subscribers for subscription television. In early 1982 there were approximately 330,000 customers receiving MDS television programming.

Cable TV has been the most successful of all the alternative television distribution methods. Almost all cable television companies now use two or more satellite reception antennas and all the associated electronics to receive programming from satellites. Signals from these "headends" are cabled to subscribers who have a channel selector, and often a decoder, on their television sets. In early 1982 approximately 28% of all households in the United States were hooked into a cable TV system.

SMATV stations are simply small cable TV networks operating in a single mobile home park, apartment, or condominium complex. The unique characteristics of such systems are that they are self-contained and serve only properties that do not cross public thoroughfares. SMATV systems must use commercial-grade equipment to receive satellite signals directly from space and a relatively small cable network to distribute the programming. This form of distribution of programming is not regulated except by the program producers, who may either scramble the signals or refuse to sell their programming to the SMATV company managers. Because the future promises many services in addition to common TV programming, such as burglar alarms, home banking, home shopping, and newspapers via television, a well-installed SMATV system will be compatible with future advances.

The market potential for SMATV is immense because of the recent rapid drop in the price of satellite television receiving stations. This form of reception and distribution is growing rapidly, so that an estimated 20% of cable TV subscribers in Dallas, Texas, now receive service from SMATV installations. It is also estimated that only 20% of the 23 million multiple dwelling units in the United States were serviced by cable TV in 1982. Since these figures do not even include many trailer communities that will be reached by cable lines only in 10 to 15 years, SMATV is assured a stronghold in our television entertainment future.

Economics of the New Television

Consumers should be aware of the diverse programming available today when selecting any television service. Although most of the television distribution firms receive nearly all programming from satellite, the selection of programming relayed to the consumer varies considerably. This was not so in the late 1960's when the major television networks owned nearly all aspects of broadcasting, including program selection, production, scheduling, and in some cases, transmission. Local stations usually broadcasted network programs with a few local shows. However, the emerging climate of deregulation and the supportive technology of satellite telecommunications make innovative broadcasting possible. Unlike any previous time, those with innovative financing and creative ideas are now able to broadcast nationally and even internationally from a single uplink station. When communication between satellites becomes commonplace, tens or hundreds of programmers broadcasting internationally may emerge to allow consumers even more diverse and original shows.

Broadcast television for mass audience consumption is only one aspect of the market place for television relays by satellite. Many possibilities of alternative, highly profitable programming are in conceptual, planning, or implementation stages. For example, the American Hospital Video Network links 7000 American hospitals to continuous medical education and health-care news. This network will produce approximately 30% of its programming and will subcontract the remaining amount to independent producers. There is also a rapidly expanding realm of information transfer for teleconferencing, computer-to-computer relays, and corporate-owned, corporate-used systems. For example, Hewlett Packard owns and operates it own telecommunication system. Telephone expenses have reportedly been reduced $50,000 per month, while their telecommunications system can also be used for other functions.

These broadcasts directed towards the general public are financed in three principal ways. Some programming is available free of charge. In an effort to relay their message as widely as possible, most religious programmers do not charge their audience. Other networks also offer their services free to the public, but sell advertising time to commercial sponsors as does network television. For example, the Financial News Network, FNN, was viewed free of charge by an estimated 20 million households in 1982 while advertising from hotels, airlines, banks, credit-card companies, commodity brokers, and others who wished to reach a targeted audience paid the bills. A third variety of programmers such as Home Box Office and Showtime charge monthly subscription rates. In the same fashion, some one-time special events are sold individually to the public by broadcasters.

The viewer of the "new TV" is experiencing a metamorphosis in advertising as well as in programming content. Flexible commerical formats such as five-minute, "soft-sell" interludes named "informercials" can target large audiences at relatively low cost. Cable television advertising revenues are expected to rise dramatically from $129 million in 1981 to a range from $150 milliion to $500 million in 1985. Experts estimate that advertising receipts will rise to as high as $2.5 billion by 1990. On the other hand, network TV sold $12.7 billion in advertising in 1981. This was substantially more expensive than time on the "new TV." For example, a 30-second spot commerical on an extremely popular network show, such as "Dallas," cost $175,000 in 1981, while the same block of time on Music Television (MTV) cost $1000.

The public learns of new developments in the industry through publications such as TV guides, which list programming and satellite assignments and contain general-interest articles. Industry publications are similar but do not carry program listings, as they often cater to specific groups. For a complete list of such publications see Table 5-1.

TABLE 5-1 **A Selection of Industry Publications**

Name	Address	Description
Broadcasting Magazine	1735 DeSales St., N.W. Washington DC 20036 (202) 638-1022	Weekly—programming overview including radio and TV and general information about the broadcasting industry
Cable Age	TV Editorial Corp. 1270 Avenue of the Americas New York, NY 10020	Monthly—information for the Cable TV industry
CableVision	Titsch Publishing, Inc. 2500 Curtis Street Denver, CO 80205	Monthly—information for the Cable TV industry
Channel Guide	P.O. Box 2027 Denver, CO 80150 (303) 761-7930	Weekly—rundown of satellite programming and TVRO news
Communications News	Communications News 124 S. First Street Geneva, IL 60134	Monthly—detailed articles about the whole telecommunications business
Coops Satellite Digest	P.O. Box 100858 Ft. Lauderdale, FL 33310 (305) 771-0505	Monthly—general information for home TVRO owners

Multichannel News	Fairchild Publications P.O. Box 1124 Dover, NJ 07801 (303) 393-6397	Weekly—general overview of cable TV industry
Orbit	CommTek, Inc. P.O. Box 1700 Hailey, ID 83333 (208) 788-4936	Monthly—rundown of programming as well as in-depth stories on the industry and the cable business
Private Cable	Weisner Publishing Co. 5594 S. Prince St. Littleton, CO 80120 (303) 798-1274	Monthly—general information and news about the SMATV, MDS, LPTV, etc. businesses
Satellite Communications	Cardiff Comunications 6430 S. Yosemite Street Englewood, CO 80111 (303) 694-1522	Monthly—trade journal for the commercial satellite industry
Satellite Dealer	CommTek, Inc. P.O. Box 1048 Hailey, ID 83333 (208) 788-4936	Monthly—industry news and developments for earth station dealers
Satellite TV Opportunities	1717 E. University Ave. Oxford, MS 38655 (601) 126-5510	Monthly—marketing ideas and company profiles in satellite communications business
Satellite TV Week	Fortuna Communications P.O. Box 308 Fortuna, CA 95544 (707) 725-2476	Weekly—programming guide and general information about satellite TV
SatGuide	CommTek, Inc. P.O. Box 1700 Hailey, ID 83333	Monthly—trade journal for the satellite programming industry
Satellite News	Phillips Publishing 7315 Wisconsin Bethesada, MO 28014	Weekly—newsletter about satellite industry
Satellite Week	TV Digest 1836 Jefferson Pl. Washington, D.C. 20036	Weekly—coverage of satellite industry
Satellite TV Guide	P.O. Box 8266 Edmonton, Alberta T6H 4P1 (403) 425-1169	Weekly—rundown of satellite programming

Satellite TV Magazine	**501 N. Washington St. Shelby, NC 28150 (704) 482-9673**	**Monthly—general interest articles about satellite industry**
Westsat Channel	**Westsat Communications P.O. Box 434 Pleasanton, CA 94566 (415) 846-7380**	**Bimonthly—lists all of domestic satellites and transponder assignments plus other information**

Types of Programming

Cable TV and the other television distribution systems air a wide variety of programs, which can be grouped into general categories. More detailed descriptions of programming and planned networks can be found in the literature outlined in Table 5-1.

News and Weather

News and weather programming, often interspersed with general-interest programs such as segments on food or fashion, is provided in a 24-per-day format. An all day news/weather station has advantages over a network that airs this information for brief periods. Selected news is repeated throughout the day to allow the viewer constant access; as the news changes during the day, updates are released; and as weather conditions change, the viewer is quickly informed.

The pioneer news and weather service was Ted Turner's Atlanta-based Cable News Network (CNN), which was joined by an all news sister station (CNN2) in 1981. Competition in this area is keen. For example, a joint effort of Westinghouse Broadcasting (which owns the nationally based Group W news service) and the ABC Network called Satellite Channel News (SCN) has entered the field. Another such endeavor was formed when the Eastern Broadcast Service purchased UPI's Newstime to create North American Newstime (NAN). This service relays audio and individual full-color photographs by using slow-scan technology rather than full-motion video. NAN uses a portion of the signal that is relayed to a satellite by WTBS in Atlanta to transmit UPI information. It employs their news-gathering facilities of photos, slides, audio reports, and news wires to serve, primarily, newspapers and news offices.

Innovative weather forecasts using sophisticated color computer graphics cover national and local weather developments continuously. One such service available to local cable TV broadcasters is View Weather, which uses a scramble signal that is delivered along with the WTBS, Atlanta video signal. Operators can choose from a variety of programming including local weather reports, traveler's forecasts, aviation weather, weather history, general climatological data and statistics, agricultural weather reports, and standard national forecasts.

Business and Financial Programming

Business and financial programs concentrate on concerns of the economy. Two types of programming exist. Reuters News Service and the BizNet American Network are examples of pay-only, scrambled business information service. There are also the free, commercially supported ventures such as the Financial News Network (FNN), which contain more general information than the more narrowly-targeted pay-only programming. Business and financial shows relay up-to-the-minute stock and commodity market reports as well as continuous computer graphics and ticker-tape displays. Perspectives on business trends, daily financial news, and reports on many other speculative markets satisfy a more general audience.

Movies

Recently released, uncut films of high quality are offered by some programmers for a monthly fee. Such "premium" programming is among the most appealing to many customers.

Sports Programming

Sporting events such as football, basketball, baseball, tennis, soccer, and hockey supplemented with special-interest stories and coverage are available via satellite. Many sources, such as ESPN, the 24-hour sports cable network, offer these events. USA Cable, as well as superstations WTBS, Atlanta; WGN, Chicago; and WOR, New York, periodically broadcast sporting events. Some local cable stations sell broadcasts of single regional sports happenings to local audiences, while special events broadcast via satellite are occasionally sold nationally on a one-time basis.

Children's Shows

Both educational and entertainment programs targeted exclusively toward young audiences are available via satellite over channels such as the Spanish International Network (SIN), WTBS, Atlanta, and some religious networks. The cable service, Nickelodeon, is devoted

exclusively to the education and entertainment of children. The new programming is in general non-violent and of high quality and has been compared favorably in caliber to the highly regarded "Sesame Street."

Religious Programming

Religious programmers broadcast a variety of events related to organized religious practices and spiritual learning. The programs function both to serve the followers and to raise funds for the churches through donations. In fact, the broadcasts are lucrative enough that some cable TV operators have been offered payments to carry programming in order to increase these donations. Networks that do not attempt over the air solicitations are the National Christian Network (NCN), the Eternal World Network (EWTN), and the National Jewish Television Network (NJT).

The largest private video downlink network for any use is being built for the Morman Church. This network, comprised of over 500 earth stations, will be used primarily for the reception of church communications and functions.

All the religious networks use the miracle of satellite telecommunications.

Adult Entertainment

Programs targeted at an adult-only audience supply all but hardcore pornography. Pay services, such as Playboy Enterprise's Escapade; Penthouse Magazine's PET; and Private Screenings are the major contributors.

Music

Music television productions are new to the medium. Primarily rock music is interspersed with creative video effects and action. These productions are so popular that most newly released albums from well-known artists are now accompanied by video productions. These programs, relayed by networks such as Music TV (MTV) are targeted to the audiences of ages 12 through 34 which comprises in excess of 30% of the national viewing market. Because MTV airs 8 minutes per hour devoted to commercials, this material is offered free to operators.

In addition to MTV, a wide range of audio-stereo services, such as the Satellite Music Network and WFMT/Fine Arts Radio, carry their signals on sidebands of television communication circuits. The networks ABC, NBC, and CBS now link their radio stations via satellite.

Family Programming

Family programs are composed exclusively of wholesome material that excludes sex and violence. For example, the Home Theatre Network carries family shows and is available as pay television 12 hours per day. Four of the twelve hours are devoted to travel programs, with the remaining time given to drama, comedy, musicals, adventure, and children's films.

Special Interest

Special-interest programs cater to a clearly defined, narrow market segment. For example, the Spanish International Network and its venture, Univision, is geared to the Spanish culture, while Daytime produces programming aimed specifically at the American Woman. As a joint venture of ABC Video Service and the Hearst Corporation (publisher of such magazines for women as Good Housekeeping, Cosmopolitan, Harper's Bazaar, House Beautiful, and Town and Country), Daytime produces broadcasting in areas such as nutrition, health, cooking, relationships, and parenting. Another special-interest network, the Black Entertainment Network, targets the interests of black Americans. The American Satellite Network provides movies for hotel chains only.

Political Programming

The network C-Span is publicly owned and broadcasts directly from the U.S. Congress. In addition to congressional happenings, it provides coverage of other public events in the nation's capital. It is both a media for politicians and a source of information for the discriminating electorate.

Educational

The American Educational Television Network has an audience of approximately 30 million people who receive credits for "going to school" via TV. Most viewers are professionals who must periodically update their knowledge. The network charges relatively high rates for "informercials" that are directed at these highly targeted audiences.

Programmers and Satellite Assignments

Table 5-2 lists the satellites designed for transmission of video broadcasts to the United States and Canada. As the number of transponders are increasing, so are the number of television shows. All programming is assigned to one or more transponders or relays aboard the telecommunication satellite. Each transponder is allocated a given microwave frequency and polarization so that an earth station may tune to any desired channel by chosing a satellite, a frequency band, and a feedhorn polarization.

Video Satellites

Orbital Location(°W)	Early 1982	Mid-1982	Early 1983	Mid-1983
143	Satcom		Satcom V	Satcom V
139			Satcom I-R	Satcom I-R
134				Galaxy I
131	Satcom III-R	Satcom IIII-R	Satcom III-R	Satcom III-R
127		Comstar D4	Comstar D4	Comstar D4
123	Westar II	Westar V	Westar V	Westar V
119	Satcom II	Satcom II	Satcom II	Satcom II
114	Anik A2/A3	Anik A2/A3	Anik A2/A3	Anik A3
112				Anik A2
109	Anik B	Anik B	Anik B	Anik B
104		Anik D1	Anik D1	Anik D1
99	Westar I	Werstar I	Westar IV	Westar IV
95	Comstar D2	Comstar D2	Comstar D2	Comstar D2
91	Westar III	Westar III	Westar III	Westar III
87	Comstar D3	Comstar D3	Comstar D3	Comstar D3
83	Stacom IV	Stacom IV	Satcom IV	Satcom IV
79	Westar 1 and 2	Westar 1 and 2	Westar 1 and 2	Westar I 2
72				Satcom II-R
70				Spacenet II

Table 5-2

6. IS IT LEGAL?

Is it legal? This seemingly simple question has arisen regarding many of the new technologies, markets, and business forms in the growing telecommunication field. The proliferation of low-cost earth receiving stations is accompanied by questions of "freedom of the airways" and legal battles about "pirating." Important questions about who may own satellite communication channels have been raised. The new technology has encouraged many investors to enter the communication business and has blurred the distinction between the responsibilities and regulation of the participants. These are among many issues that often lead to legal confrontations and re-evaluation of the telecommunication business. In the past ten years changes have so rapidly occurred that the previously enacted legislation, the 1934 Communication Act, has become very much outdated. In the process of writing new legislation, the U.S. House of Representatives Subcommittee on Telecommunications conducted a comprehensive examination of telecommunication policy, which included the following:

> "An examination of the effects and status of competition and deregulation; an analysis of the electronics and telecommunications industries and their role in world trade; an investigation of Western Hemisphere and International issues; a look at the panoply of emerging home and business information technologies; scrutiny of the role that the federal government plays in telecommunications policy development, including federal, state, and local jurisdictional disputes,...the possibility of deregulation in international telecommunications services, the reaction of Third World countries to the development of a global information system, concerns over privacy and trans-national electronic mail, and the future roles of Comsat and Intelsat in international communications."

Pirating or Right?

The labelling of some consumers of broadcast television as "pirates" has as its basis the debate about economic rights of programmers, program distributors, and consumers. Many consumers have argued for "freedom of the airways." When private reception of satellite broadcasts from American programmers was outlawed in Canada by its federal government, the right to free airways was forcefully stated by a Canadian politician: "The law is an ass, if that is the law,...If somebody wants to put a signal down in my backyard, nobody can tell me not to look at it." On the other hand, programmers and distributors incur considerable expenses to bring television to the public and deserve a just return on their investments. If too many consumers pirated pay-television signals, programmers and distributors would either suffer financial losses or be forced to sell commercial time. The legal questions concerning private reception of satellite signals are further complicated because many other broadcasts are offered free by religious programmers or by commercially sponsored networks. Owning a home earth station to receive freely relayed programming is legal. New legislation specifically prohibiting consumers from owning TVROs would have to be passed especially for pay-TV broadcasts.

The legal right of individuals to receive satellite signals depends on interpretations of both copyright and communication laws. The copyright laws which were updated in 1976 to include video and cinematic entertainment, protect producers and television distribution companies who request payment from customers who receive their broadcasts. Also, while Section 605 of the 1934 Communication Act prohibits the "interception and unauthorized use" of private television programs over public airways, an interpretation suggests that those who use but do not resell transmissions are within bounds of the law. The battle over this issue became heated after the FCC 1979 ruling eliminated license requirements for earth stations that do not transmit, but only receive, satellite signals. In the early fall of 1980, a Congressional amendment, "theft of service" legislation, prohibiting private reception of satellite signals by thousands of low-cost installations was defeated on the grounds that this law would hamper development of satellite technology or even direct broadcast systems. The lobbying organization for owners of home earth stations, the Society for Private and Commercial Earth Stations (SPACE), which spearheaded the defeat of this amendment, argued that three classes of citizens who watch TV have been created. They are "those who have paid their bills, those who haven't, and those who aren't allowed to." Although there are numerous instances of private earth station operators offering to pay programmers for their services, at least one supplier has returned subscription payments citing contracts that limit them to

servicing only the cable television industry or a lack of policy on dealing with individuals. The argument often used is that collecting small monthly bills from thousands of individual subscribers scattered around the country would cost more than the revenues received. SPACE and the National Satellite Cable Association (NSCA), an association formed to represent owners of small "mom and pop" cable TV systems, have also argued that people in rural areas should have the same program-viewing opportunities as the urban American. They claim that many rural Americans without the use of private TVRO earth stations would not be able to purchase cable TV, multipoint distribution system (MDS) broadcasts, or subscription TV (STV) at any price.

Many people in the spirit of pioneers insist on freedom of the airways and the right to receive signals directly from satellites. As noted earlier, most of these "pioneers" are willing to pay the programmers for their services. The policy of SPACE is two-fold: "Every individual has the right to receive any information transmitted through the air; and that information intended to be paid for must be paid for - not stolen." The Canadian ban on receiving American satellite broadcasts had not deterred an estimated 700 private users from doing just that by 1982. A prominent Canadian politician advised his federal government, "If a signal is falling on your property and you don't want it, ask them (the Americans) to take it off. If you want to compete, then turn out better programs." Eventually, in March of 1983, the Canadian government lifted the ban on use of private earth stations. Too many pirates were ignoring such prohibition.

Programmers are more willing to sell their broadcasts to parties who service many customers than to individuals. Cable television companies have purchased material from these programmers for years. In fact, both the cable and program-production businesses have grown together. Satellite master antenna television (SMATV) companies, who are capturing an increasingly large share of the cable TV market but who still have far fewer subscribers than do cable television companies, often can purchase quality programming. However, some producers of "premium programming" who refused to sell their product to SMATV companies were sued in 1982 by the State of Arizona for violating anti-trust laws. The NSCA has even argued that some large, franchised cable operators are pressuring their affiliated program suppliers in an attempt to keep the small operators of cable and SMATV out of the business.

In contrast, bars and restaurants equipped with satellite receiving stations are seldom able to purchase such "premium programming." While they can legally air free programming such as Music Television, other broadcasts of entertainment channels such as Home Box Office

(HBO), and most first-run movie networks, are not available. Some programmers would rather sell individually to all the bar patrons via home-based cable television networks and thus earn substantially higher revenues than by selling once to each bar. In fact, before HBO introduced its scrambling system it had systematically and successfully sued bar owners. The convicted pirates were often required to pay a penalty of three months of their revenues to the network.

Answers to legal questions about pirating of subscription television (STV), multipoint distribution system (MDS) broadcasts, and low-power television (LPTV) were seemingly more complicated because these services are not relayed from satellites and are also subject to a "free-airways" interpretation. STV signals have been scrambled in codes so simple that a host of companies, especially in California, were founded just to sell decoders to "pirates." Although these companies have been acquitted in a number of law suits aimed at curtailing their sales, some state and municipal governments have passed legislation outlawing their activities. Also, Section 605 of the 1934 Communication Act has been successfully used to outlaw unauthorized reception of MDS or STV on the ground that these broadcasts were not intended "for the use of the general public." Nevertheless, although numerous injunctions have been issued to stop sales of equipment to receive MDS broadcasts, many thousands of homes still have the small microwave dish and electronics necessary to intercept these programs for free. In June of 1982 HBO, the major MDS broadcaster, first successfully sued an individual in Minneapolis for pirating. Before this action only equipment manufacturers were sued. The recent introduction of LPTV stations, which will also scramble broadcasts, opens up a new market for pirates and manufacturers of decoding equipment.

Pirating of television broadcasts can be curtailed by the incorporation of more sophisticated scrambling and decoding devices into distribution systems. "Smart" addressable decoder/converter devices are being used by some broadcasters so that codes can be periodically changed to stop reception of pay-TV programs. Thus, solutions to television pirating will probably not lie in the judicial process as use of more sophisticated encoding systems for protecting pay-TV broadcasts becomes commonplace.

Just how much pirating occurs? It has been estimated that in 1982 10 to 20% of all cable TV transmissions have been stolen, resulting in an approximate loss of $3.5 million of revenues per month. In contrast, in 1982 privately owned satellite reception stations have been estimated to be less than two-thirds of one percent (0.66%) of homes receiving cable television. Programmers' losses of approximately $60,000 per month caused by those pirating signals from satellites were much less than those caused by cable pirates.

The Right to Satellite Circuits

Until the mid 1970's the distinction between broadcasters and "common carriers" was clear. Common carriers transmitted audio and video signals from point to point over relatively long distances for paying customers. Broadcasters had distributed audio and video messages from one point to a local market at no cost to the consumer. The roles of common carriers and broadcasters has become less clearly defined in relation to satellite telecommunications, so that the applicability of the 1934 Communication Act has been questioned and new legislation is being studied.

The FCC regulates the use and ownership of transponder circuits in its effort to protect the public interest as mandated in the 1934 Communication Act. In the 1970's the FCC required that satellite operators meet technical and economic requirements as well as serve the public interest. However, applicants were not expected to have a common-carrier status as a condition for launching and operating a communication satellite. The demand for transponder circuits was sluggish until the early 1980's, so users simply leased these relays. As the demand grew, sale of the full-time use of a transponder to the highest bidder became a viable business alternative. In an effort to be as free from FCC regulations as possible, operators argued that they were not common carriers, since the transfer of a transponder to a user is not an offer of a service for hire to the public. To further support the argument that they should not be governed by the existing communication legislation, they contended that the sale of a transponder was not really a sale, but a pre-paid, protected lease, and that the satellite owners actually retain control over maintenance and operation of the complex vehicles.

Sales of transponders began in the early 1980's, partially as a result of the success of these arguments, and partially as a result of the FCC policy to allow a competitive industry to emerge. On November 12, 1980, the Western Union Telegraph Company informed the FCC that it had completed a contract with Citicorp, a large New York bank, that included an option to purchase a transponder aboard the Westar satellite. On December 11, 1980, Citicorp exercised this option. On March 11, 1981, Hughes Communication Incorporated informed the FCC of its intent to sell transponders on its newly authorized Galaxy space vehicles. RCA Americom, as one of the companies that later sold transponder space, in November, 1981, auctioned the use of these circuits on its Satcom IV satellite in order to realize a return based on market value, not on cost. This auction would have earned RCA $90.1 million for the sale of seven transponders, with $14.4 million coming from the highest bidder, had not the FCC ruled three months later that the

process was unfair and unacceptable. Many of those who were unable to purchase or lease time on Satcom IV took RCA to court for redress of lost cable TV revenues.

The method of allocating satellite communication circuits has been a subject of considerable debate. Operators argue that by selling transponders and realizing a higher return on the expensive business of building, launching, and operating a satellite, they would encourage a rapid expansion in satellite capacity. In fact, by granting approval to launch an additional twenty satellites at the beginning of the 1980's, the FCC has an avowed policy of creating such a competitive and profitable environment. Transponder users argue that the purchase of communication circuits would permit improved business planning. Others contend that sales will squeeze out the smaller, less richly financed entrants in the telecommunication business who cannot afford the market prices but who might be able to afford regulated prices. It is possible that the number of satellites and thus satellite transponder circuits will outpace demand in the latter 1980's so that some of these problems will be more manageable. In any case, the FCC approved sale of transponders on a case-by-case basis in August 1982. Vendors of these satellite circuits will not be considered common carriers.

Regulation or Deregulation

Both the broadcast industry and the common carriers have been carefully regulated. In the early, simpler days of radio and television, the FCC was called upon to regulate only over-the-air broadcasts. Regulation of the giant common carriers was also less complicated because the services offered by AT&T and a few competitors were more clearly defined.

The proliferation of innovative broadcasters and the development of satellite communication technology has raised many questions. For example, will low power television aimed at serving special-interest groups in metropolitan areas interfere with cable TV or network television signals? Should the FCC even attempt to regulate competition between subscription television, multipoint distribution systems, cable TV, and the video cassette industry, all of which are aimed at the metropolitan consumer? Are two-way addressable home communication systems the business of cable operators, the local telephone company, computer firms, or other businesses?

The large common carriers such as AT&T are now capable of entering much of the communications business. These new entries raise many regulatory problems. For example, how well can some of the new long-distance telephone services compete in a deregulated market with AT&T, which owns essentially all of the terrestrial long distance networks, is establishing its own satellite communication system, and

has a budget larger than most nations of the world? Newspaper publishers who rely heavily on advertising fear that AT&T's entry into competitive markets could lead to the creation of an "electronic Yellow Pages" that could significantly decrease their advertising revenues. The future will certainly provide many unexpected answers to these complicated questions.

7. THE FUTURE

Satellite telecommunication is changing rapidly. New technologies and new uses for these technologies are constantly being discovered. By 1985 the number of satellites surrounding our globe will probably double to over 200. Novel forms of television such as direct broadcasting systems can cause revolutionary changes in the television industry. Videoconferencing, a recent introduction, is tying our globe even closer together, and as a result is allowing many new and established businesses to experience rapid growth. These additional uses of satellite communication add to the demand for satellite transponder circuits. This rapid growth emphasizes the need for international cooperation in allocating orbit space and developing technologies that increase communication capacity.

Direct Broadcast Systems

Direct broadcast systems (DBS) for relaying television directly from satellites to millions of small rooftop antennas stem from years of technical developments, and were received with an excitement unchallenged in the history of television. The joint American/Canadian Communications Technology Satellite experiments in the latter half of the 1970's demonstrated that using higher-frequency microwaves for relaying signals to relatively small antennas was feasible. As a result, in 1982, Canada took the lead in implementing the first limited-scale, but fully operational, DBS system broadcasting to remote rural locations. In the United States the FCC, in response to interest expressed by the private sector, requested and received by the July 16, 1981 deadline proposals from fourteen ventures to design, build, and operate direct broadcast television systems by as early as 1985.

How Does DBS Work?

What is a direct broadcast system and why is it unique? Direct broadcast satellites relay higher-frequency 14/12 gigahertz transmissions to

antennas ranging from 2½ to 6 feet in diameter. These dishes are much smaller than those required for conventional, lower-frequency, 6/4 gigahertz broadcasts because DBS satellite antennas have more restricted footprints and therefore have higher EIRPs. In addition, each transponder aboard a DBS satellite can generate approximately 200 watts of power, which is 20 to 40 times greater when received on earth than that of transponders relaying lower-frequency conventional broadcasts. Such power levels allow small DBS antennas the capability of receiving high-quality television pictures.

All DBS broadcasts are scrambled. Therefore subscribers must pay a monthly sum plus, in some cases, an initial fee to purchase an antenna and the electronics necessary to decode the satellite signal. Unlike private reception of conventional satellite broadcasts, the charge that individual subscribers must pay to receive DBS programs is an integral part of the designed service. However, this expense may rapidly fall in the next few years. Some businesses involved in manufacturing and operating the necessary antennas and electrical equipment forecast that the cost for a mass-produced, complete DBS satellite receiving station could be as low as $200 or $300 by as early as 1986. Comparable costs in 1982 were as high as $1000. If such is the case, the unique advantage of broadcasting via satellite to a national audience using convenient, low-cost reception equipment can make DBS an attractive method for distributing television programming.

Will DBS be Successful?

The success of any form of broadcast television depends upon how conveniently and at what cost quality entertainment and information can be viewed. The consumer, in general, does not care which technical mechanism delivers this programming. Just as predictions that television would kill radio and that cable television would kill conventional television were unrealistic, so are the expectations of some that DBS will eliminate cable television and conventional broadcasts. Each alternative mode of broadcasting will capture a share of the television viewing market, which itself has many specialized components. For example, DBS and conventional home earth receiving stations have no competition in the completely rural areas, while cable television is most profitable in the large cities. However, for the free market to work properly it is important that every broadcasting mode is controlled by fair and equitable regulations.

The growth of direct broadcast systems is being influenced by many forces. First, the cost of earth station terminals will ultimately determine the potential market share of DBS television. Complete terminals should cost less than $600 to $800 (in 1982 dollars) for DBS to be competitive. Second, the sooner DBS operators can implement their

sevices, the better they will fare in competition with cable TV and low power television (LPTV), which are both rapidly growing. Third, even though DBS has a unique advantage in remote areas, the growth of LPTV in more densely populated rural areas may be stiff competition.

The outcome of the competition between DBS, LPTV, cable TV and conventional TV for new markets is hard to predict. A significant market for new broadcast forms does exist because, in early 1982, one million American homes had no television service and 2.3 million had only one channel. While the new LPTV airs locally originated programming, transponders dedicated solely to this broadcast mode will also make nationally originated programming available. The National Association of Broadcasters, the lobbying arm of conventional network TV, has expressed the worry that LPTV and network television relaying commercially sponsored local programming might not be able to survive on local advertising money alone if much of the lucrative nationally directed advertising was sold to exclusively national broadcasters such as DBS. However, DBS sponsored by advertising may be in a weaker position than DBS functioning as pay TV. Of the 94 million households projected to receive television in 1990, most direct broadcast systems would be enormously successful if they had 3 to 5 million subscribers. But why would an advertiser who could easily reach 10 million homes through cable or conventional television limit the targeted audience to 3 or 4 million unless air time was substantially less expensive? Obviously, the division of the television viewer market is difficult to predict.

Cooperation rather than competition between DBS and other broadcast modes is possible. Direct broadcasts can be relayed into cable TV, LPTV, or satellite master antenna systems for distribution. Cable TV companies, which are already organized to service millions of subscribers, might be in ideal positions to install and maintain DBS equipment. The cost for such services may well be one of the largest that DBS operators have to face. If DBS operators can air unique programming, the chance that their services will be purchased by other broadcast modes is certainly higher.

Who are the DBS Operators?

In 1981 Comsat filed a massive proposal with the FCC to provide three channels of DBS service to an estimated 35 million homes. A separate entity, the Satellite Television Corporation (STC) was formed to own and operate the system of 6 proposed satellites, 4 to span the entire United States and 2 to remain as in-orbit spares. By the July 16, 1981, FCC deadline, thirteen other companies had submitted detailed proposals. Three additional companies, United Satellite TV, Oak Satellite Corporation, and Satellite Syndicated Systems, Inc., filed for DBS

authorizations after the cut-off date. The DBS Corporation proposed to operate as a DBS carrier offering free TV to subscribers but charging programmers as much as $1000 per hour for each broadcast channel. Other companies also had unique aspects to their plans. Western Union envisaged using the 11.7- to 12.2-gighertz band instead of the 12.2- to 12.7-gigahertz band proposed by all other participants. Focus Broadcasting planned to lease space on Western Union's advanced Westar satellite to make experimental services available one to two years before competitors and to serve only Miami, New York, Los Angeles, San Francisco, and selected rural areas. CBS proposed using a new form of digitally relayed television called "high definition television," which would result in a much clearer picture than conventional TV. Details of some of these proposals are outlined in Table 7-1.

1981 U.S. Direct Satellite Broadcasting Proposals

Company	Satellites	Channels per Satellite	Dish Size	System Cost ($ million)	Service
CBS	4	3	39″	N.A.	Advertising & Pay
Direct Broadcast Satellite Corp.	3	14	35″	725	Common Carrier
Focus Broadcast	1	1	29″-59″	53 Yr.(lease)	Advertising & Pay
Graphic Scanning	2	4	23″-39″	136 (1 sat)	Pay
RCA	4	6	23″-39″	775	Common Carrier
Satellite TV Corp.	4	3	23″-35″	683	Pay
Hubbard Broadcasting	2	4	35″	234	Advertising
Western Union	4	4	15″-35″	516	Comon Carrier
Oak Satellite Corp.	4	12			Pay
Satellite Syndicated Systems	4	6		529	Pay

Table 7-1

Many countries have considered implementing direct broadcast systems. Canada has operated a limited-scale DBS system since 1981. The United Satellite Corporation, a subsidiary of British Aerospace, GEC-Marconi, and British Telcom, plans to implement a DBS system via the Britsat satellite in 1986. Two channels will be relayed to 2 1/2-foot antennas on the British Isles and to dishes as large as 9 feet on the European continent, which would be in a weaker footprint area. The Japanese, among the leaders in studying high-frequency satellite broadcasts, are planning their own DBS television. Italy, France, and Germany expect to launch their own experimental DBS satellites around 1985.

Firms that plan to build DBS earth stations are also gearing up for their design and production. Low-cost antennas are being manufactured in the 2½- to 6-foot range. Many of these businesses are selling DBS terminals that downconvert the high-frequency signals at the antenna focus and thus simplify installation procedures for DBS operators.

Direct broadcast systems may cause economic hardship to some communicators because of signal interference. For example, it has been argued that interference from DBS broadcasts in the 12-gigahertz band, used in Los Angeles for law enforcement, fire protection, paramedic units, computers, and mobile radio unit communications, could cost the city $15 million in new equipment. Others such as Home Box Office, operating multipoint distribution system television in an adjacent frequency band, might also have some similar interference problems. However, direct broadcast systems are not the only ones creating potential interference problems. Low power television stations near cable TV systems could also cause decreases in cable TV picture quality.

The first DBS service in the United States was successfully initiated by United Satellite Communications, Inc. in late 1983 reaching Indianapolis and 34 counties with five available channels. This firm plans to offer DBS programming by late 1984 in those 26 states covered by the satellite Anik C2. Other firms are just one step behind in launching their own DBS broadcasts.

The Battle for the Orbital Arc

The rapid growth and development of satellite telecommunication has sparked the interest of nations around the world. Satellites populating the geosynchronous equatorial arc can serve many countries simultaneously and are therefore the concern of all mankind. However, only so many microwave relays can orbit the earth before severe problems with interference between satellite transmissions will arise. Many

institutional and technical solutions are being incorporated into the global communication system to allow the use of a maximum amount of microwave relay circuits and to foster global cooperation.

Global Harmony?

Satellite services by nature transcend national boundaries. Since the United States is not the only country locating its telecommunication satellites on the equatorial arc, it must consider the concerns of many neighbors. Canada operates its series of Anik satellites in the same arc, and some South American countries such as Brazil, Argentina, and Columbia are planning to launch their own vehicles. When Intelsat began to regulate, own, and manage international telecommunications vehicles it did not envisage the technical developments that now permit operation of privately owned international satellite communication systems. Even the 1962 Communications Satellite Act marking the entrance of the United States into the Intelsat Organization was vaguely worded. It stated that "...it is not the intent of Congress to preclude...the creation of additional communications satellite systems, if otherwise required in the national interest."

In October 1981 the FCC approved 13 applications allowing domestic satellite systems to transmit signals across international borders. Seven petitions received by the FCC requested permission to receive data from Canada; two proposals, one filed by Satellite Business Systems and one by the American Satellite Corporation, sought to transmit to as well as receive data from Canada. Four companies requested to transmit or receive television programming to or from points in Canada, the Caribbean, and Central America. In early 1983, 15 more applications for transborder service between the U.S. and Canada, Mexico, the Carribean and Central America were approved. These actions questioned the role of Intelsat in international communications even though the decision required, as envisaged in the original Intelsat treaty, approval by all the countries involved as well as coordination by Intelsat to ensure technical compatibility with the Intelsat system and to avoid significant economic harm to this system. When Intelsat was created all member nations were expected to use the Intelsat facilities except in rare cases. However, modern satellite communication technologies have become extremely flexible. Some perceive that the issues of commercial competition, and national self-interest have now become as important as the need for organization to prevent interference and to foster cooperation.

International meetings, the 1983 Region II Administrative Radio Conference (regional WARC) and the 1985 and the 1987 World Administrative Radio Conferences (WARC) sponsored by the International Telecommunication Union, have been organized to resolve

issues relating to frequency-band allocations, international communication networks, and satellite spacing and location. The burgeoning demand for transponder circuits in the United States alone is sufficient reason for careful planning. This is further complicated because other neighboring countries use the same portion of the geosynchronous arc. The United States may have additional difficulties in coordinating its activities with international needs because the military requires that many telecommunication activities be kept secret.

The international community can choose some technical remedies to increase the number of available interference free transponder circuits. These fall into the general categories of space and bandwidth conservation. If satellites relaying as many channels as technically possible and operating in multiple frequency bands were spaced more closely together, more transponder circuits could be made available. This can be achieved by eliminating the need for excess satellites by direct inter-satellite communication, by improving the effectiveness of satellite use by switching between multiple beams, and by using techniques to squeeze as much information as possible into each portion of the allocated bandwidth.

Satellite Orbital Spacing

Spacing satellites closer together increases the potential number of available transponders, but can possibly result in serious problems with both uplinking and downlinking interference. There is a trade-off between the extra cost of ground-station equipment and increasing the number of available satellite circuits. As satellites are spaced closer together, more expensive, larger antennas with more directional, narrower beamwidths must be used to avoid signal degradation due to interference.

The issue of satellite spacing was not seriously considered until 1980. RCA Americom had been operating two satellites, Satcom II at 119°W., and Satcom I at 135°W., while Western Union had three Westar vehicles at 91°W., 99°W., and 123.5°W. In addition, a joint venture of AT&T and GTE had leased the entire capacity of Comstar General's fleet, Comstar I at 128°W., Comstar II at 95°W., and Comstar III at 87°W. A tentative policy had allocated 6/4 gigahertz band and 14/12 gigahertz band satellites to a minimum of 4° and 2° spacing, respectively. In October, 1981, the FCC surprised the industry by requesting public comment on the possibility of authorizing spacing of satellites along the North and South American portion of the geosynchronous arc at 2° intervals.

Some of the techniques for spacing satellites closer together depend on signal polarization and satellite power levels. If a signal from one satellite is relayed with polarization opposite to that of a signal occupying the same bandwidth originating from an adjacent satellite, then interference between these signals will be less and, as a result, spacing can be reduced. This technique is based on the property of cross-polarization discrimination. This is the ability of an earth station feedhorn to receive stray signals occupying the same frequency band but having different polarizations at power levels 50 to 200% less than such signals having the same polarization. Since each 24-transponder satellite has alternating channel polarization, this method of using cross-polorization discrimination by interweaving polarization between satellites reduces additional interference due to closer satellite spacing. Another method of satellite coordination can also be used to allow closer orbital spacing. This is based on the fact that power levels varying between communications vehicles are related to the quantity and to the type of information relayed. For example, while one transponder can relay hundreds of audio messages or one television broadcast, another circuit that carries two television broadcasts or one television broadcast plus a number of audio subcarriers will necessarily have higher-power microwaves. Also, higher power signals are more resistant to interference but more able to cause interference with like signals from adjacent satellites. Therefore, a coordination technique used to reduce interference in a telecommunications relay circuit is to allocate adjacent orbital positions to satellites that relay different types of information and that have different power levels.

Many industry comments on the FCC request for responses to the possible change to 2° spacing discussed such techniques. The National Cable Television Association declared it could accept 2° spacing if polarization interweaving was incorporated and if high-power satellites were spaced a minimum of 3° apart. They claimed that without these measures the present-day fleet of 15-foot antennas used to receive satellite broadcasts would have to be replaced by at least 23-foot-diameter dishes at a cost to the consumer of at least two million dollars. A NASA official and a Comsat spokesperson felt that an FCC ruling would be meaningless without Canadian and South American cooperation. Most industry respondents argued for a "go-slow," careful regulatory approach, while some expressed serious doubts about the technical feasibility of 2° spacing. However, not all respondents expressed concern. In fact, Satellite Business Systems requested permission in April of 1982 to launch its fourth and fifth 14/12 gigahertz satellites in 1984 and 1986, respectively, so it would space its five vehicles in 2° intervals from 92°W to 100°W in the geosynchronous arc.

In April, 1983 the FCC approved 2° orbital spacing for satellites operating in both the C- and Ku-bands. This decision, to be imple-

mented gradually by reducing spacing to 3° at first, will eventually double the capacity of the orbital arc.

Higher Frequency Microwave Transmissions

The trend towards the use of progressively higher radio wave frequencies has characterized the history of modern communications. The earlier commercial geosynchronous satellites operated in the 6/4 gigahertz portion of the C-band allocated by the FCC (see Table 7-2). Ku-band transmissions were experimentally investigated in the late 1970's by the use of the Japanese/Ford Aerospace, Sakura CS series and the Canadian Anik B series of satellites. NASA, in concert with the Public Service Satellite Consortium and the Canadian government, also participated in Ku-band experiments with one of the Anik satellites (also named the Communications Technology Satellite, CTS). Commercial broadcasts in the Ku-band began in Canada in September of 1979, while the Ku-band satellite SBS-1 was the first commercially demonstrated in the United States in August of 1981. Today, numerous American Ku-band communication vehicles for use in all forms of communications including DBS television have either been launched or are in planning and construction stages.

Allocation of Microwave Frequency Bands	
Band Name	**Bandwidth (Gigahertz)**
L-band	0.39 to l.55
S-band	1.55 to 5.2
C-band	3.90 to 6.20
X-band	5.20 to 10.9
K_u-band	15.35 to 17.25
K-band	10.9 to 36.0
K_a-band	33.0 to 36.0
Millimeter-band	30.0 to 300.0

Table 7-2a

Frequency Band Allocated for Microwaves and Satellite Links and their Bandwidths			
Band (GHz)	**Bandwidth (MHz)**		**User**
2.11 to 2.13 2.16 to 2.18 3.7 to 4.2 5.925 to 6.425 10.700 to 11.700	29 20 500 500 1000		Common carrier use in the U.S.A.
3.7 to 4.2 5.925 to 6.425	550 500	downlink uplink	Commercial satellites.
7.25 to 7.75 7.9 to 8.4	500 500	downlink uplink	Government and military satellites in the U.S.A.
10.95 to 11.2 11.45 to 11.7 11.7 to 12.2 14 to 14.5	2500 250 500 500	downlink downlink downlink uplink	Mobile radio, terrestial microwave common carrier, and satellite links.
17.7 to 19.7 19.7 to 21.2 27.5 to 29.5 29.5 to 31	2000 1500 2000 1500	uplink uplink downlink downlink	Allocated, but not yet used becaused more developmental work is needed.
0.620 to 0.790 2.5 to 2.6 11.7 to 12.5 22.5 to 23 41 to 43 84 to 86			Direct broadcasting satellites. The first three bands are being used today in several areas, while the last three bands are under experimental development.

Table 7-2b

Using higher-frequency microwave bands for communication satellites has some distinct advantages. Since these transmissions use antennas more efficiently, smaller receiving dishes can be used. However, perhaps the most important reason for using Ku-band transmissions is the possible expansion in the number of available communication circuits. Ku-band and C-band relays are invisible to each, other so signals can be sent to and from two satellites at the same location with absolutely no interference. Experimental investigations in the even higher frequency Ka-band are leading to commercial satellites in the future and thus to another quantum jump in available transponder circuits.

Co-Location of Satellites

Satellites can be located at the same position in the geosynchronous arc if they operate in different frequency bands or if the receiving and

transmitting antennas of each are pointed in widely different directions. For example, in 1981 the 135°W. location was populated by five vehicles dedicated to three different services: broadcasting, defense, and meteorology (see Table 7-3). Of the three defense satellites that operate in the 8/7 gigahertz band, one was a replacement for a similar vehicle, while the third had a very different footprint pattern from the other two. A South American country could have co-located a 6/4 gigahertz satellite at 135°W. if the footprint was very different from the American vehicle and if the satellite receiving antennas operated in different frequency ranges.

Some Co-Located and Nearby Satellites		
Satellite Description	**Location**	**Frequency Band (GHz)**
	Co-Located	
Defense Satellite Communication—DSCS-11-F11 System - serving Eastern Pacific	135°W	8/7
Defense - serving Eastern Ridge—NATO 111-B	135°W	8/7
Meteorological Surveys—GOES/SMS	135°W	2.1/1.7
Broadcast TV—Satcom I	135°W	6/4
Defense - serving Eastern Pacific—DSCS-11-F14	135°W	8/7
	Nearby	
Broadcast TV—Satcom III	132°W	6/4
SPC-F1	132°W	6/4
SPC-H-3	132°W	6/4
Defense—DSCS-11-F9	130°W	8/7
Broadcast TV—Satcom V	140°W	6/4
SPC-F4	140°W	6/4

Table 7-3

In the future, clusters of non-interfering, co-located satellites could be relayed information by only one uplink facility. In addition, all these vehicles could conserve resources by sharing a single platform,

positioning system, and power supply. Such a rigid platform to which all the vehicles would be attached would probably also improve the stability of all the satellite antennas and therefore enhance overall performance.

Intersatellite Communication

Presently, television or other forms of high-density communications are relayed across the Pacific or Atlantic Oceans either by transoceanic cable links or by an Intelsat satellite. Newly developed fiber-optic transoceanic cables, one of which can carry 4000 telephone conversations or more than 10 television broadcasts, are being considered by the FCC for installation in 2 to 5 years. The Intelsat V satellite now positioned over the Atlantic Ocean can either relay 40 high-quality color TV broadcasts, transmit 2 million telex channels, manage more than 13,000 two-way phone calls, or send 5 trillion digital bits of information in an hour, which is equivalent to transmitting the entire Encyclopedia Brittanica in 6 minutes.

Furthermore, satellite circuits can be used even more effectively by communicating directly between satellites with microwave or laser beams. This method works very well in outer space because there is no atmosphere to weaken signals bouncing between satellites. In fact, the FCC and the International Telecommunications Union have already allocated the frequency bands for intersatellite communications. Using such intersatellite relays could make communication between very distant countries less expensive by eliminating an intermediate link (see Figure 7-1). For example, a message uplinked in San Francisco could be received by a satellite over the American arc, relayed directly to a satellite positioned over the Mediterranean, and downlinked to Saudi Arabia. The alternative would be to use an intermediate Intelsat satellite or a submarine cable, which would probably increase the cost of communication.

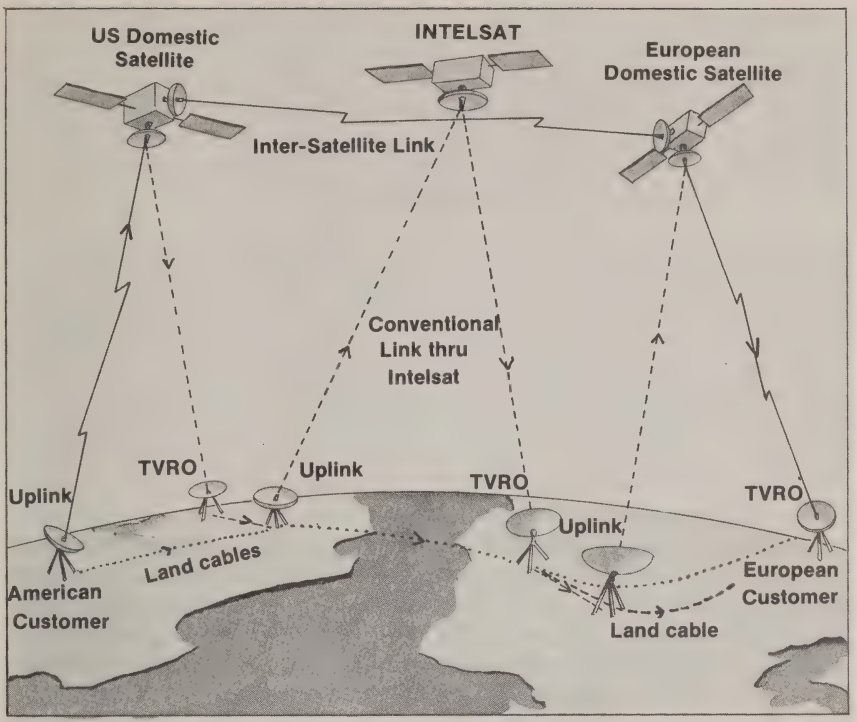


Figure 7-1 Intersatellite Communication. A direct link between an American and a European domestic satellite would greatly simplify long range communication.

Switching Between Multiple Beams

Satellites that switch between differently targeted antennas on command and thus select from predefined footprints allow the available bandwidth to be used more efficiently. This is because they contribute a potential source of downlink interference to targeted regions only. Besides, such communication relays can employ the available power more effectively by restricting their output to limited areas. The first such vehicle on the drawing board is the European Space Agency's L-Sat platform satellite. Similarly, satellites can use one or more moveable antennas to target selected, local areas.

Efficient Use of Bandwidth

Until recently, television and radio broadcasts have always been relayed in analog forms, nearly unchanged since the mid 1960's. Their only improvements have been in reliability, stability, and power capacity. In early 1980 most satellites still relayed analog broadcasts, using one transponder per customer at a given time. However, more than one

message could be transmitted by each transponder if more than one carrier wave was put into action, a method termed "frequency division multiple access" (FMDA), or as it is more commonly known, "multiplexing". At the beginning of this century telephone companies introduced multiplexing so that existing wires previously used for just one conversation would transmit multiple calls per wire. As a result, one cable can now carry up to 20,000 phone calls.

New techniques for relaying as much information as possible in each frequency band are being developed to make more efficient use of satellites. Digital forms of coding and relaying messages previously applied only to computer-to-computer conversations are now increasing satellite communication capacity. These new techniques are also relatively immune to terrestrial interference and have very low noise levels. One of the more promising digital methods making transponder circuits more efficient is termed "time division multiple access" (TDMA). TDMA is comparable to time-sharing of computers in which many parties can simultaneously use one computer because each actually uses the computer for brief intervals. TDMA use of transponders is technically more demanding than FDMA because all the earth stations served must be carefully synchronized as they are sequentially turned on and off. However, TDMA reduces interference between signals being relayed by the same transponder and allows more than twice the information to be transmitted as compared with analog relays. For example, the simultaneous transmission and reception of alternating pictures, a method developed by CBS, can relay two television broadcasts per transponder with TDMA. Furthermore, Intelsat has recommended that all its member nations use a speech processing technique, Digital Speech Interpolation, which uses TDMA transmission so that four telephone calls can be relayed over the same bandwidth that previously could transmit only one conversation. Other digital techniques for using bandwidth as efficiently as possible are evolving to relay information such as high definition television (HDTV). HDTV pictures approach the quality of films because 1125 lines (in one experimental HDTV system) instead of 525 are "painted onto" the face of a television set. The required bandwidth of 150 megahertz, which would be necessary with conventional analog relays of HDTV, might be reduced to 50 megahertz by the use of digital coding and transmission techniques. Digital methods are also making inroads in all other forms of satellite communication. For instance, ABC, CBS, and NBC are beginning the process to ultimately relay all their network radio stations via digital satellite transmissions.

Teleconferencing and the Office of the Future:

Since the day that Alexander Graham Bell had the first telephone conversation, which marked the occasion of the first teleconference,

the "let your fingers do the walking" method has been the least expensive and most prevalent communication tool. The time and energy saved by the telephone is incalculable. This saving is now taking other forms. As television, computers, fiber-optic cables, and satellite relays have been evolving, they are bridging the gap between broadcast television and teleconferencing, as well as between the office and the home. And so a new era in communications has been born.

Teleconferencing methods fall into three broad categories. Audio conferencing is communication by telephone or by any other voice communication device. The simplest audio conference is a two-way telephone call. However, modern switching technology allows simultaneous connection of as many phones as necessary. Further, there are many technical options, such as voice-actuated speaker phones, one of which can be placed on a conference table to receive and send conversations. More sophisticated "studio-quality" devices are also available.

Computer conferencing is communication over telephone lines between computer terminals. Any number of terminals can be interconnected, since not all participants need to be in attendance simultaneously because each computer terminal can "memorize" any incoming data for later digestion. This form of teleconferencing has additional flexibility since participants can be polled on any specific point and the memorized data can be thoroughly analyzed.

Video teleconferencing, or video conferencing, communicates through pictures or full-motion television in addition to audio. An explosive growth in video conferencing is underway because the necessary high-frequency, broadband communication is available via fiber-optic and coaxial cables, line-of-sight microwave relays, and, most significantly, the satellite. The Quantum Science Corporation has recently projected that the total market for equipment and transmission services will expand from $16 million in 1981 to nearly $380 million in 1985. Both audio conferencing and video conferencing have enormous potential since 96% of all residences and offices in the United States have telephones linked to a common network.

Video conferencing can be categorized as either a full or an interactive teleconference. The full video conference involves all parties in two-way transmission of audio and video messages as illustrated by the PBS network program, the MacNeil/Lehrer Report, in which participants in New York and Washington see each other on large-screen televisions. In an interactive video conference, messages are relayed from a single uplink location to multiple receiving points. Interactive teleconferencing is used more frequently when many participants are involved because the number of uplink sites is usually limited. Often, questions may be relayed back to the central focus by telephone.

Video conferencing should ideally allow all participants to have the most effective communication possible. Messages originate in a television studio leased from a local station, a hotel conference room, or a corporate board room, all of which can be equipped with remote-control cameras and microphones when simplicity or privacy are necessary. Arrangements may be made for a variety of special features such as facsimile transmission of documents, slide or movie presentations, or "electronic blackboards" that transmit writing to a receiving screen. With these requirements and organizational needs for establishing the communication link, adjusting equipment, and scheduling, the complexity may parallel that of a well-produced television show.

The needs of a particular meeting must be assessed to determine whether full-motion, color video, or the much less costly freeze-frame or slow-scan video is required. Slow-scan technology can relay a television picture every 10 to 90 seconds in contrast to a full-motion video signal which "paints" a snapshot on the television screen 30 times every second. Because the decreased information density permits use of a much narrower bandwidth than with full-motion television, slow-scan signals can be sent over ordinary telephone lines. Slow-scan video conferencing can be perfectly adequate for communicating information in a format such as a medical education seminar in which a voice and descriptive charts, photographs, and X rays are communicated.

In many instances, teleconferencing can improve the quality and lower the costs of communicating between distant parties. Meetings "by satellite" can be held between widely separated parties at short notice. Travel time and expense are drastically reduced, especially if large numbers of participants are involved. For example, a 1981 Ford Motor Company teleconference brought 17,000 dealers in 38 locations "together" for a simultaneous introduction of new car models for 1982. Teleconferencing is also finding important applications in medical education, in the exchange of medical information, or even in the diagnosis of illnesses. In fact, the first live international overseas television message between the United States and Europe via the Intelsat, Early Bird satellite on June 28, 1965, was of an open-heart surgery. The earliest uses of audio conferencing over 40 years ago were in the health care field as well.

The broadest application of video conferencing has been in the private business sector, resulting in significant improvements in productivity and reductions in cost. Although businesses place more importance on accurate, rapid decisions than ever before, office productivity in the last decade rose only 4% while industrial productivity rose 90%. Teleconferencing can increase office productivity by improving the flow of information and by reducing non-productive time spent in travel. For example, M/A-Com, a high-tech conglomerate with subsid-

iaries scattered throughout the United States, held 15 video conferences each week in early 1982. Recent surveys indicate that video conferencing could replace 5 to 15% of all business meetings that require significant amounts of travel. However, many meetings in a stressful or a high-stake situation, such as in contract negotiations, require face-to-face contact. Nevertheless, video conferencing is much more effective than audio conferencing when visual input is necessary to "get a feel" for the substance of the information being communicated.

The growth of business teleconferencing has an interesting sidenote. As increasing energy costs have caused higher travel costs, which increase the incentive to teleconference, hotels and motels have lower bookings. In order to offset this decrease in revenue, some large national and international hotel chains are establishing teleconferencing studios. For example, Intercontinental Hotels, owner of more than 100 hotels in 50 countries, in conjunction with Comsat General, is installing video conferencing facilities and equipment.

The popularity of teleconferencing has some negative aspects. It has been projected that the rapid growth of teleconferencing will strain the transponder market by requiring as many as 3500 satellite circuits by the end of this century. Some people have also suggested that the rapid move towards teleconferencing may not be the best allocation of scarce transponder space. Another criticism sometimes expressed and possibly based on personal preferences is that many executives, businessmen, educators, and professionals would simply rather travel. Others who have participated in teleconferences relayed to wide audiences have expressed an interesting reaction that is not necessarily a criticism. Following wide exposure via such a video conference, some have experienced "the Hollywood effect," i.e., not knowing people who seem to know them.

Teleconferencing technologies are a key element in the office of the future. More efficient uses of available bandwidth are being developed. For example, in early 1982 an RCA scientist invented a device for relaying 2-way full-motion video conferencing over a single transponder instead of over two as was previously required. Signal scrambling techniques are being perfected to ensure privacy in transmitting information such as sensitive business plans. Sophisticated remote-controlled TV cameras, audio monitors, and special service equipment for allowing private meetings are being built. As a result, homes and offices can be linked by telephone, television, and computers whose memories can store whole libraries. Teleconferencing certainly has an important role to play in our expanding communication system.

Private Business Networks

Today, many businesses are competing to introduce low-priced, high-performance equipment for communicating voice, data, and video information. New markets such as DBS or home receiving stations, which were non-existent ten years ago, have been created by these technical innovations. Satellite communication has made costs much less sensitive to the distance between the sender and the receiver than they were 20 years ago when land-based methods had to be used. As a result, the distinction among local, regional, domestic, and international markets has blurred, and new business opportunities have emerged.

The telecommunication web is being woven by a host of technologies. Cities can be laced with broadband networks of coaxial and fiber-optic cables connecting homes and businesses. These threads can also be connected to line-of-sight microwave relays, satellite uplinks, or satellite receiving stations. Such networks can relay any type of information desired to any type of modern reception equipment, such as computers, televisions, telephones, or facsimile devices, and can be interconnected in many conceivable ways.

Among the businesses emerging as a result of these flexible communication systems, perhaps the most familiar are local and national telephone companies. The largest of these, AT&T, were surprised in the early 1980's by competition in the long distance phone business from MCI, Incorporated and Southern Pacific Corporation when both realized the business opportunity provided by the new, flexible technology. Similarly, local cable television companies compete with the older, more established conventional television broadcasters. New firms such as the American Satellite Corporation, Satellite Business Systems, M/A-Com, and GTE Communications, which provide services similar to the established common carriers, are selling access to their all-digital, high-speed communication networks. Satellite Business Systems, for instance, operates its own fleet of 14/12 gigahertz satellites to transmit TDMA digitally encoded signals carrying voice, data, and video images. Some larger corporations are establishing privately owned networks for relaying internal, corporate information. An example is Citicorp, the large New York-based bank, which spent $60 million on telecommunication in 1980. In an attempt to cut costs it has established its own network to link eight hundred offices by messages sent over two Citicorp-owned transponders aboard the Westar V vehicles.

The most convincing sign of the continuing growth in the telecommunication business is the tremendous amount of money spent both in space and on earth. As a result, the number of satellites and earth

receiving stations has dramatically risen. Over 30 satellites have been launched by American interests since 1974 while over 2 billion cumulative dollars have been spent to date in the United States earth and space segments. The pace of this growth will almost certainly continue to quicken.

8. CAREERS AND OPPORTUNITIES

The rapid growth of satellite telecommunication has created opportunities for enterprising people. New businesses have emerged and many new jobs have been created. The first step in participating in this exciting field is to understand its technology and its far-reaching effects on many parts of our society. Then the choice of career paths can be more clearly seen.

Today, the most pressing demand is for communication technicians and engineers to design, build, and operate satellites, earth stations, and all other inter-connecting equipment. The level of education and experience varies widely from job to job as illustrated by these following examples. Highly skilled electrical engineers are needed to design sophisticated electronic equipment. Technicians who can be trained in a matter of months are required for installing earth stations or cable lines. Television networks, businesses, and other users of satellite communication rely on experienced personnel to oversee the operation of their equipment and to be available to correct any unexpected problems. The new, rapidly growing forms of television broadcasting such as direct broadcast or multipoint distribution systems will require hundreds of installation and maintenance crews.

There are many opportunities for sales personnel in satellite communications. Readers of this book will have an advantage over many less informed but successful salespeople already working in this field. The information presented here will enable the salesperson to not only know the answers to many questions asked by perspective customers but also to understand the many markets serviced by satellite communication. For instance, satellite master antenna television (SMATV)

alone has a vast market waiting to be tapped. Although competition for SMATV subscribers is becoming fierce in some regions of the country, there will always be a need for competent and aggressive people. Other businesses such as those servicing the home TVRO market are also rapidly growing. The same marketing talent can be used to sell home TVRO systems, low noise amplifiers, cable TV subscriptions, or transponder time on-board satellites.

Competition for many more general positions in the satellite communication business is greater than that for technical or sales experts. For example, financial officers, accounting specialists or personnel recruiters need to have much less special training. Similarly, television actors or cameramen face the same stiff competition in the new television stations as they do in conventional TV business even though there are some more positions available. However, those who do understand the emergent businesses may have an advantage in being able to act more quickly in responding to new career opportunities.

Many have chosen the high risk-high return route in attempting to start their own businesses. There have been some notable success stories in recent years among those who have caught the entrepreneurial fire and have launched either manufacturing or service businesses. Many excellent opportunities still exist for those who can see a small distance into the future.

APPENDIX A

THE DECIBEL NOTATION

Decibels (dB) are used to express the relative powers of two signals and are defined as follows:

$$\text{Decibel difference in power levels} = 10 \text{ logarithm } \left(\frac{\text{Signal A}}{\text{Signal B}}\right)$$

For example, if signal A is 100 watts and signal B is 1 watt, then signal A is 20 dB stronger than signal B because

$$10 \log\left(\frac{100 \text{ watts}}{1 \text{ watt}}\right) = 10 \times 2 = 20$$

Therefore, if an amplifier received a signal of 1 watt and increased its strength to 100 watts, it would have a gain of 20 dB. Using the same formula we can calculate the gain of any antenna or amplifier.

Occasionally, the abbreviations dBm and dBw are encountered. These refer to how strong a signal is relative to milliwatts (thousandths of a watt) or watts, respectively. For example, if a power level is expressed as 20 dBm it means 100 mwatts signal; 30 dBw means a signal 30 decibels stronger than one watt or 1000 watts.

APPENDIX B

Technical Glossary

Amplifier A device used to increase the power of an electrical signal.

Analog Describes a system or device in which signals vary continuously, instead of in steps. See "digital."

Antenna A device that collects and focuses electromagnetic energy. This process results in an energy gain, proportional to antenna surface area.

Antenna Efficiency A measurement of how much of the radiation intercepted by the antenna actually is captured by the feedhorn.

Automatic Gain Control (AGC) A circuit that locks the gain to a fixed value by compensating for temporary shifts in gain caused by temperature or other changes.

Audio Subcarrier The carrier radio wave that transmits audio information between 5 MHz and 8 MHz.

Automatic Frequency Control (AFC) A circuit that prevents drifting away from a chosen frequency by locking the receiving unit onto that frequency.

Azimuth (AZ) The horizontal pointing angle of an antenna measured clockwise in degrees from true north.

Bandpass Filter A circuit or device that allows only a specified band of frequencies through a device.

Bandwidth(B) The frequency range to which a carrier wave is assigned.

Baseband An information or message signal whose content extends from a frequency near DC to some finite value. For voice, baseband extends from 30 hertz (Hz) to 3400 Hz. Video baseband is from 50 Hz to 4.2 MHz.

Beamwidth The angle through which an antenna looks at signals from a transmitter. This is equal to the width in degrees of the main lobe.Side lobes unlike the main lobe see extraneous noise instead of signal from the targeted satellite.

Block Downconverting The process of converting the entire frequency band of a signal to a lower radio frequency range such as 70 megahertz.

Buttonhook Feed A waveguide shaped like a question mark directing signal from the feedhorn to an LNA behind the dish.

C-Band The 3.7- to 4.2-gigahertz satellite communication band.

Carrier A single frequency radio signal that is modulated to carry information long distances through space.

Carrier-to-Noise-Ratio (C/N) The ratio of the received carrier power and the noise power in a given bandwidth, expressed in decibels. This figure is directly related to G/T (ratio of antenna gain to system noise temperature) and S/N (ratio of signal to noise levels). In a video signal, the higher the C/N, the better the received picture will be.

Carrier-to-Noise Ratio (C/kT) This ratio is expressed in decibels per hertz of bandwidth. C/kT, another measure of carrier-to-noise ratio, is C/N divided by the signal bandwidth.

Cassegrain Feed System A radiating system that includes a primary reflector ("dish"), a secondary reflector, and a feedhorn. Named for Nicholas Cassegrain, a 17th century French physician who invented a telescope using this principle.

CATV Community Antenna TV. Also called Cable TV. The system has a central antenna tower (VHF/UHF/FM) plus a satellite TV dish antenna that receives high-quality broadcasts for subsequent sale through a signal distribution system, generally via coaxial cables, to each customer.

Channel A segment of bandwidth used to establish a communications link.

Clark Belt The orbital belt in which geosynchronous satellites are situated.

Coaxial Cable A cable for transmitting high-frequency electrical signals that is composed of an internal conducting wire surrounded by a non-conducting dielectric material, which in turn is encircled by a grounded wire shield.

Continuous Tuning A method of selecting transponder frequencies by continuously varying a circuit element such as a resistor.

Decibel (dB) A term that expresses the ratio power levels used to indicate gains or losses in a system. Also used to express absolute power levels such as dBm or dBw.

$$dB = 10 \log \left(\frac{\text{Signal A}}{\text{Signal B}} \right)$$

Decibel (dBm) Decibels relative to milliwatts of power, i.e. signal B is one milliwatts.

Decibel (dBw) Decibels relative to watts of power, i.e. signal B is one watt.

DBS Satellite broadcast system that beams several TV channels directly to homes equipped with earth stations. Frequencies used are in the Ku-band and antennas can be approximately 3-feet in diameter.

Demodulate A process in which information is recovered from a carrier wave.

Demodulate A process in which information is recovered from a carrier wave.

Detent Tuning Selection of transponder channel by adjusting a variable resistor on a receiver (See continuous tuning).

Digital Describes a system or device in which information is transferred by electrical "on-off" or "high-low" pulses instead of continuously varying ("analog") signals.

Dish Slang for a parabolic microwave antenna.

Dish Illumination The portion of the dish and, occasionally, the surrounding area, from which the feedhorn can receive signal or noise.

Downconverter A device that selects and lowers the frequency of a received signal.

Downlink An earth receiving station.

Dual Orthomode Coupler A device that can simultaneously detect the vertically and horizontally polarized signal for relay to two LNAs.

Earth Station A complete satellite receiving or transmitting station including antenna, electronics, and all necessary cables.

Effective Isotropic Radiated Power, (EIRP) The power level measured in each direction leaving the satellite. The power is highest at the center of the beam and decreases at angles away from this beam center.

Elevation Angle The vertical angle measured from the horizon to which an antenna must be pointed to send or receive satellite signals.

F/D Ratio The ratio of antenna focal length to antenna diameter.

Feedhorn The device mounted at the antenna focal point that collects signals reflected from the dish.

Focal Length The distance from the reflective surface of a parabolic dish to the point at which incoming satellite signals are focused (see focal point).

Focal Point Point toward which a dish reflects and concentrates signals from a targeted satellite.

Footprint The geographic area toward which a satellite downlink antenna directs its signal. The relative measure of strength of this footprint is the EIRP.

Frequency The number of vibrations per second characterizing a radio wave.

Gain The magnification of output relative to input signal.

Gain-To-Noise Temperature Ratio (G/T_{sys}) A figure of merit of an antenna and low noise amplifier expressed in decibels per degree Kelvin; the larger the value of G/T_{sys}, the better the reception capabilities of the earth station.

Geodetic South True south found after adjusting for compass errors caused by magnetic deviation.

Geostationary Describes a satellite in orbit 22,300 miles above the equator and which revolves around the earth with velocity equal to that of the earth's rotation. The satellite's position relative to the earth's surface is constant, so little or no ground antenna tracking is needed.

Geosynchronous Movement in an orbit at the same speed at which the earth rotates.

Gigahertz (GHz) Billions of cycles per second.

Ground Noise Noise received from the ground.

Hardline Type of low-loss coaxial cable that has a continuous metal shield instead of a conductive braid.

High Power Amplifier (HPA) A device that provides the energy for carrier amplification necessary to transmit to the satellite.

Intermediate Frequency (IF) A frequency in a receiver or transmitter system that enables easier filtering, distribution, modulation, and demodulation of a signal.

Isolator Allows signal to pass in one direction but attenuates or reduces the strength of signals moving in the opposite direction.

Degrees Kelvin (°K) Temperature above absolute zero graduated like the celsus, °C, scale. Used as a figure of merit to express equivalent noise in amplifiers and other parts of satellite systems. The lower the temperature, the lower the noise. 0° = **-273**°C = -459×F.

Ku-Band The microwave frequency band between 11.7 to 12.2 gigahertz.

Line Amplifier An amplifier in a transmission line that compensates for signal attenuation or losses.

Low Noise Amplifier (LNA) A device that amplifies the received signal at an earth station. The LNA is usually mounted on the antenna.

Local Oscillator (L/O) A device used to supply a stable single-frequency signal to an upconverter or downconverter. The local oscillator signal is mixed with the information-carrying signal to change its frequency up or down.

Low Power Television (LPTV) Low-power conventional, multichannel, over-the-air television broadcasted to a much smaller and local audience that conventional over-the-air TV.

Magnetic Deviation Degree difference between true north and north compass reading.

Master Antenna TV (MATV) Broadcast receiving stations that use high-quality UHF and VHF antennas centrally located and that provide TV programs for a local apartment/condo or group-housing complex.

Megahertz (MHz) Millions of cycles per second.

Modem A contraction of modulator/demodulator. Usually a device that combines the modulation and demodulation functions in a single unit.

Modulation A process in which message information is imposed on a carrier. This can be done by the varying of a carrier parameter such as frequency, the number of vibrations per second, or amplitude, the strength of the carrier signal.

Mount Structure that supports an earth station antenna. Frequently used types of mounts are polar mounts, azimuth/elevation (AZ/EL) mounts.

Multipoint Distribution System (MDS) Local, line-of-sight transmission of 2-GHz microwave broadcasts received by randomly scattered, small rooftop antennas.

Noise Unwanted radio signals.

Noise Figure (F) The ratio of the actual noise power generated at the input of the amplifier to that which would be generated in an ideal resistor. The lower the noise figure, the better the device.

Noise Temperature (T) Used to measure the amount of thermal noise present in a device or system. The lower the noise temperature, the better the device.

Orthomode Transducer (OMT) A device attached to the antenna feed that permits using the antenna for simultaneous transmission and reception without mutual interference. The device is polarization selective; thus, the transmit and receive signals must be on different polarizations, usually orthogonally (90°) related.

Pad Slang term for the foundation upon which the antenna is mounted; usually reinforced concrete.

Parabola Geometric shape that has the property of reflecting all signal parallel to its axis to one point.

Polar Mount Antenna mount that permits all satellites in the geosynchronous arc to be scanned with movement of one axis. Elevation angle is fixed in a polar mount.

Polarization A characteristic of the electromagnetic wave in space. Four senses of polarization are used in satellite work: horizontal linear, vertical linear, and right-hand and left-hand circular. The satellite and earth station polarizations must match, and an antenna feed adjustment is made at the time of installation to match the horizontal or vertical polarization of the satellite antenna. No adjustment is required for circular, except that both antennas must be for right-hand or left-hand circular.

Prime Focus The point toward which a parabolic reflector directs and concentrates the signals it receives from a satellite targeted along the antenna axis.

Redundant Refers to a complement of "stand-by" equipment that can be switched on either manually or automatically when a unit in use fails.

Reflector The antenna's main curved structure, or "dish," which collects and focuses a signal onto either the secondary reflector (Cassegrain) or the feed (Prime Focus).

Radio Frequency (RF) Generally describes an electronic signal above the baseband or intermediate frequencies.

Sidelobe A undesired response of an antenna that causes signal radiation or pickup in an undesired direction. Excessive sidelobes reduce antenna efficiency and can increase reception of interference from other communication systems.

Single Channel Per Carrier (SCPE) A satellite transmission system that employs a separate carrier for each channel. As opposed to frequency-division multiplex system that can combine up to near two thousand voice channels on a single RF carrier.

Signal-To-Noise Ratio (S/N) Ratio of the signal power to the noise power in a specified bandwidth, usually expressed in decibels.

Skirt A 6- to 48-inch metal ring mounted on the perimeter of a dish parallel to its axis to reduce interference.

Splitter A device that takes a signal and splits it into two signals.

Thermal Noise Random, undesired electrical signals caused by molecular motion known as heat.

Threshold Extension Demodulator (TED) A scheme for lowering the threshold of FM (frequency-modulated) demodulators, permitting operation of the system with a lower C/N without impulse noise or interference showing on the picture.

Teleconference An electronic meeting accomplished, in the case of a video conference, by the connection of parties via television.

Threshold A minimal signal to noise input required to allow a video receiver to deliver an acceptable picture.

Transponder A microwave repeater (receiver and transmitter) in the satellite used to amplify and change frequency of a received band of signals. Domestic satellites employ either 12 or 24 transponders, which typically have a 36-megahertz (MHz) bandwidth. (One megahertz = 1 million cycles per second.)

Trap An electronic device that absorbs or rejects unwanted signals.

Television Receive-Only (TVRO) An acronym for a satellite TV receiver or earth station, which consists of a satellite antenna, a low noise amplifier (LNA), and one or more receivers.

Upconverter A device that increases the frequency of a transmitted signal.

Uplink The earth station transmitting to the satellite.

Video Monitor A television that requires only an unmodulated baseband signal to reproduce a picture.

Voltage Standing-Wave Ratio (VSWR) VSWR x $\frac{E_{max}}{E_{min}}$ is the ratio between the maximum voltage expressed as the sum of the incident and reflected voltages and the minimum voltage expressed as the difference. This expresses how much signal is lost by reflection in components of an earth station.

Zenith The pointing of an antenna at an elevation of 90°; the straight-up position.

Revolutionary changes in the way man communicates are providing many new careers and opportunities for financial gain and creative satisfaction.

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Dr. Frank Baylin studied physics at the University of Pennsylvania. While conducting research and teaching he completed an MBA at the Wharton School of Business. He has contributed to a number of high technology fields and has published numerous articles. In recent years his business and technical consulting services have proved valuable to the communication industry.

Amy Toner, a fine arts graduate from the University of Colorado and a photographer and writer, offered a unique contribution to this book. She reviewed and rewrote portions of the manuscript to ensure that it would be clearly understood by the non-technically educated reader.

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